UNIVERSITY OF GOTHENBURG

DEPARTMENT OF CONSERVATION

DELAMINATING PAINT IN AN 18TH CENTURY CANVAS WALL PAINTING

A Case Study at the von Echstedt Manor

Lisa Bandgren

Degree project for Master of Science with a major in Conservation
2021, 30 HEC
Second Cycle
[2021:26]

Delaminating Paint in an 18th century Canvas Wall Painting
A Case Study at the von Echstedt manor

Lisa Bandgren

Supervisor: Kerstin Lyckman Gevert
Degree project for Master of Science with a major in Conservation

UNIVERSITY OF GOTHENBURG
Department of Conservation

ISSN 1101-3303
ISRN GU/KUV—21/26—SE

UNIVERSITY OF GOTHENBURG
Department of Conservation
P.O. Box 130
SE-405 30 Gothenburg, Sweden

http://www.conservation.gu.se
Fax +46 31 7864703
Tel +46 31 7864700

Master's Program in Conservation, 120 ects

Author: Lisa Bandgren
Supervisor: Kerstin Lyckman Gevert

Title: Delaminating Paint in an 18th century Canvas Wall Painting
A Case Study at the von Echstedt Manor

ABSTRACT

This study investigates the cause and progression of the ongoing deterioration in a canvas wall painting from the 1760s in the Green Chamber at the von Echstedt manor. In an area approximately 170 x 170 cm on the south wall, the paint is severely delaminating despite several attempt to consolidate it. In the same area the paint is also significantly darkened. The painting is examined in situ and documented in UV-light, raking light and with a usb-microscope. Samples are collected for microscopy and material analysis. Cross sections are made from the paint samples. Two cross sections are analysed with SEM-EDS for pigment identification. The pigment used for the ground layer is identified as chalk. The prevailing pigments in the paint layers are identified as lead white and malachite, other pigments present seem to be carbon black and verdigris. Signs of lead soap formation are seen in the SEM-EDS analysis together with the SEM-BSE images. Samples of paints and varnish are analysed with FTIR-ATR to determine their molecular composition. The binder used in the ground is probably an animal glue, and in the paint layers the binder is identified as an oil. A varnish applied in the 1950s is a mastic varnish. The unregulated indoor climate of the Green Chamber is monitored over six months (Oct – Apr) and show an RH up to 88%, with daily fluctuations around 10% and a temperature down to -8 °C. Archival records are searched for information on previous treatments. A photograph from wallpaper removal during a restoration in the 1950s show extensive paint losses in the area of the painting that today is suffering from delamination. It is concluded that the paint losses from the 1950s wallpaper removal have created an area of the painting that is more sensitive to both climatically induced deterioration and lead soap formation.

Title: Delaminating Paint in an 18th century Canvas Wall Painting
A Case Study at the von Echstedt Manor

Language of text: English
Number of pages: 52
3-5 Keywords: Delaminating Paint, Canvas Wall Paintings, Material Analysis

ISSN 1101-3303
ISRN GU/KUV—21/26--SE

Acknowledgements

I would like to thank my supervisor Kerstin Lyckman Gevert for her support and for interesting discussions through the project. I would also like to thank Delia Rösel for doing the SEM-analysis with such great care, and Austin Nevin for discussing the FTIR results.

Lastly, I want to thank Cecilia Skoglund for so generously sharing her great knowledge and experience from many years of working with the wall paintings at the von Echstedt Manor. This project would not have been possible without your support and advice.

Contents

1. INTRODUCTION

1.1. Background

This thesis investigates the cause and progression of the deterioration of the wall paintings in the Green Chamber in the von Echstedt manor (*von Echstedtska Gården*) in Smedbyn in Värmland, Sweden. The von Echstedt manor was built in the 1760s and the interior of the main building and the garden houses were vividly decorated with rococo style paintings. The estate was acquired by the County Museum of Värmland (*Värmlands museum*) in 1939 and became a governmental listed building, *statligt byggnadsminne*, in 1964 (Cederlund 1995). Restoration of the buildings and of the interiors, including the wall paintings in the Green Chamber, has been carried out mainly in two time periods, 1955-1957 and 1992-1994. During the restoration 1955-1957 the wall paintings on the west and north walls were replaced by replica paintings. The wall paintings investigated in this study are the original paintings on the east and south walls. In an area approximately 170 x 170 cm on the left side of the painting on the south wall, the paint layers are suffering from severe delamination despite several attempts to consolidate the paint. Other areas of the paintings are not deteriorating to the same extent. There is no heating or climate control system installed in the main building.

The von Echstedt manor is one of the best-preserved profane Carolean and rococo style houses in Sweden. The preservation of the buildings and interiors is of great importance for both the national and regional cultural history (Länsstyrelsen 2007b). If the deterioration of the wall paintings in the Green Chamber will continue, art historical and aesthetic values risk being lost, and the entirety of the Green Chamber would be ruined.

1.2. Objective and Research Questions

The objective of this research project is to investigate and enhance the understanding of the ongoing deterioration of the wall paintings in the Green Chamber. The aim for the investigation is to create a thorough scientific knowledge base for a future treatment plan.

The main research question investigated in this study is:

- What is causing the deterioration of the wall paintings?

The main research question is divided into the following sub-questions:

- What is the composition of the original and non-original materials in the wall paintings?
- What impact may external factors like the unregulated indoor climate and possible historic accidents or events have on the materials present?
- What is the relationship between the factors involved in the deterioration of the wall paintings?

1.3. Methodology

In the conservation field, a case study is an in-depth investigation into a single object or a group of objects. In a single object study the results are only applicable to the study object, although a single object study also can be helpful in understanding similar objects or processes (Reedy & Reedy 1992, p. 23). For the purpose of investigating the research questions stated in this study, data is collected from both secondary and primary sources. Secondary sources are sources of information already collected and interpreted, while primary data is data recorded close to the event and yet to be interpreted (Walliman 2011, p. 69). Secondary sources used in this study are literature that provides the background knowledge necessary for the study (chapter 2. *Literature Review*), as well as the archival documents used in the archival research (chapter 3. *Archival Research*). Primary data is collected in the form of observations and results from material analysis and climate monitoring. Another source of primary data is the oral information gained from the museum's paintings conservator. This information is very valuable and complements the archival research in tracking historical events, as well as in placing present-day observations in context.

The method used for interpreting and analyzing the data is qualitative. A qualitative approach is often used when the problem to be explored needs a complex and detailed understanding (Cresswell & Poth 2017, p. 46). For the purpose of this study, a qualitative approach is chosen because the issue that is being explored is complex and appears to be influenced by many different mechanisms. Investigating the possible causal relations between these mechanisms require reasoning and discussion that would not fit into a quantitative research design. The data gained from the material analysis and climate measurement has the characteristics of quantitative data in that it is expressed in numbers and graphs (Walliman 2011, p. 72). However, the approach when interpreting the data is qualitative rather than quantitative. In the material analysis, for example, the aim is to understand which materials are present rather than in what amount or distribution, and to explore and discuss what role the material may play in the deterioration. The amount of analytical data is not comprehensive enough to draw any conclusions about quantities or statistics.

Observations done in the in-situ examination of the wall paintings are documented in text and photographs. The surface of the painting is examined thoroughly with bare eyes and with a head mounted magnifier. Photographs are taken with a Fujifilm X100 digital camera in normal led- light with a Kodak color control card, and in raking light for documentation of surface textures and deformations. Photographs are also taken in UV-light and with an USB field microscope, see chapter 4 *Analysis Methods* for details. Damages, retouches and sites for microphotographs and samples are mapped. MSR-dataloggers are installed in the Green Chamber to measure the relative humidity (RH) and the temperature. The dataloggers are placed at approximately two meters height at each side of the wall painting on the south wall. The datalogger to the right of the painting is placed close to the outer wall and the datalogger to the left is placed in the corner between two inner walls. The dataloggers will collect data on RH and temperature for a year to cover seasonal variations. Data will also be collected after six months of measurement.

Sampling is carried out according to The Institute of Conservation´s (ICON) Ethical Sampling Guidance and with permission from the County Administrative Board (*Länsstyrelsen*). The sites suitable for sampling are identified through the in-situ examination of the painting discussed above. A sample is only collected once a purpose for the specific sample is stated. The samples are either already loose fragments or collected adjacent to existing damage (ICON 2019). A map of the sites of sampling, together with the kind of analysis carried out for each sample, is found in appendix 1 (p. 46). Collected samples are analyzed in the lab to determine their elemental and molecular composition. The analytical methods used are described in more detail in chapter 4. *Analysis Methods*. Most samples can be saved after the analysis is done and will be organized and stored at the museum if further analysis is required in the future.

1.4. Study Object

Figure 1. The wall paintings on the east and south wall in the Green Chamber at the von Echstedt Manor. Collage of photographs taken in September 2020.

The canvas wall paintings investigated in this study are situated on the east and south wall in the Green Chamber in the von Echstedt manor and measure 163x188 cm and 188x360 cm respectively. The paintings are depicting three different landscape sceneries separated and framed by painted fields with decorative rocaille ornaments (fig. 1, fig. 4). The artist is not known.

The manor is situated on an elevation overlooking the lake Summeln and the surrounding landscape. The main building is a timbered one and a half floor building with a centered entrance and a hipped slated roof (fig. 2). According to an inscription in the entry hall in the main building, Bengt von Echstedt built the manor in the years 1762-64. The exterior of the manor has the strict symmetry typical for the Carolean period of the late 17th and early 18th centuries (Cederlund 1997). The main building and two wings on each side follow an east-west axial direction. Although the exterior is built in Carolean style, the interior is influenced by rococo, which was not uncommon practice for wealthy homes from the period (Alm 1997, p. 133). According to historical sources, the Green Chamber was the private room of Christina Catharina Echstedt, married to Bengt von Echstedt (fig. 3, fig.4) (Nilsson 2019, p. 27).

Figure 2. The main building of the von Echstedt manor, April 2021. The picture shows the east façade with the main entrance.

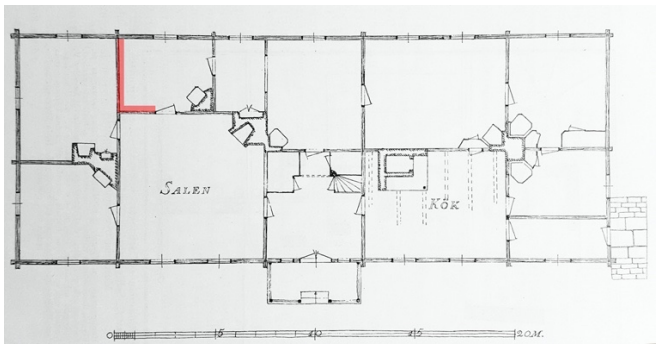


Figure 3. Plan of the main building by Gösta Selling 1926, copyright Värmlands museum. The east and south wall of the green chamber are marked in red by the author.

Figure 4. Detail of the wall painting on the south wall in the Green Chamber. Behind the clock is a replica painting from the 1950s.

1.5. Positioning and Previous Research

There are no previous technical studies that investigate what materials were used to paint the Green Chamber wall paintings or any of the other painted interiors at the von Echstedt manor. More has been written about the manor's history. Two sources especially valuable for this project are *von Echstedtska gården*, in the series *Värmland förr och nu*, published by *Värmlands museum* (Nilsson et al. 2012) and *von Echstedtska gården, Västra Smedbyn* by Cederlund (1995).

Although the study object is a wall painting, literature on canvas easel paintings is consulted for information on structure and material, for example *The conservation of easel paintings* (Stoner, Hill & Rushfield 2012). Literature used for pigment identification is mainly *The pigment compendium: a dictionary of historical pigments* by Estaugh (2004) and the series *Artists' pigments: a handbook of their history and characteristics* published by National Gallery of Art, Washington (Feller 1986). In *The organic chemistry of museum objects* Mills & White (1994) discuss both the chemical composition and deterioration of organic compounds such as binders and adhesives, which is relevant for this study. More specific on the chemistry of linseed oil paint is the dissertation *Analytical Chemical Studies on Traditional Linseed Oil Paints* by Berg (2002). The dissertation by Hermans (2017) *Metal soaps in oil paint: Structure, mechanisms and dynamics*, as well as the publication *Metal soaps in art: conservation and research* by Casadio et al. (2019), have been helpful in understanding chemical reactions between pigments and binding media. There are many articles on how these reactions may be expressed and identified in actual paintings. Articles by Keuene & Boon (2007), Keune, van Loon & Boon (2011) and

Noble, van Loon & Boon (2007) have been especially valuable for this project. The chapters by Michalski (1991) and Mecklenburg &Tumosa (1991) in the publication *Art in Transit* (Mecklenburg 1991) provide insight into the way the materials of a canvas painting may react to climatic variations that are more extreme than in the common museum environment. Another source on impact of climate on artworks and collections is the book *Climate for collections: standards and uncertainties* (Ashley-Smith, Burmester & Eibl 2013).

1.6. Ethical Considerations

Conservation Ethics is the theoretical reflections concerning conservation and conservation practice in relation to the different values ascribed to the objects (Hermerén 2019, p. 31). The Austrian art-historian Alois Riegl (1858-1905) was the first to in a systematic way describe the different kinds of values that can be ascribed to cultural heritage objects (Villers 2004). According to Riegl (1903) an object can have various values, for example historic value, art value and use value. The objects' values can change over time, and also change as people's taste and perspective changes (Riegl 1903). A conservation intervention sometimes enhances one value on the expense of another. Cleaning, for example, can remove material evidence of historic events, and adding materials such as adhesives may obstruct material analysis. All values must be taken into account and the resulting decisions are often a result of dialogue, negotiation and compromise (Muñoz Viñas 2005, p. 181). European Confederation of Conservator-Restorers Organizations (2003) state in their Code of Ethics that *the conservator-restorer shall respect the aesthetic, historic and spiritual significance and the physical integrity of the cultural heritage entrusted to her/his care* (E.C.C.O. 2003, article 5). In the Code of Ethics both tangible and intangible qualities of the objects are included as meaningful. Clavir (2009) claims that cultural significance is a social construct and, as such, its preservation may sometimes clash with the supposed objectiveness of the conservator dealing with the material aspects of the objects (Clavir 2009, pp 139-147). The use of *minimal intervention* as a guiding principle for conservation interventions emerged in the 1970s. The concept of minimal intervention emphasized objectivity and was a way to distinguish the work of the modern science-oriented conservator from that of the restorer. It is reflected in article eight in E.C.C.O.s ethical guidelines; the conservator should *limit the treatment only to that which is necessary* (E.C.C.O. 2003, article 8). The concept, or attitude, of minimal intervention has been criticized for not stating *what* is to be achieved by the minimal intervention, and under what circumstances. Opposed to minimal intervention, Villers (2004) proposes an approach that emphasize interpretive, negotiative and communicative aspect of the conservation process (Villers 2004). An attempt in that direction is the labelling of conservation practice as *management of change*. The term is being used in diverse areas of conservation such as the conservation of built heritage, paintings and contemporary art (US/ICOMOS 2003, Villers 2004, van de Vall et al. 2011).

The object investigated in this study is a wall painting, and as such it cannot be viewed as an isolated object but as an integrated part of the historic house. At the same time, the wall painting may have individual requirements for its preservation. If, for example, it is concluded the wall painting is better preserved in a climate-controlled environment, the preservation of the physical integrity of the painting would have to be weighed against the physical integrity of the building. The situation would require dialogue and compromise, as discussed above (Muñoz Viñas 2005, p. 181). Sampling for analysis means that material is removed from the object, which is an issue that requires ethical consideration. E.C.C.O.s ethical guidelines states that *The conservator-restorer shall not remove material from cultural heritage*

unless this is indispensable for its preservation… (E.C.C.O. 2003, article 15). In this study, the initial plan was to do the material analysis in situ, using equipment that would not require any sampling of material. Due to circumstances, this plan was cancelled. Instead, very small samples were collected with the purpose of identifying the materials present and investigate their possible role in the deterioration of the painting. It is assumed that, in this case, the benefit of knowing the materials compensates for the marginal material loss.

2. LITERATURE REVIEW

2.1. 18th Century Canvas Wall Paintings

The use of textile as a support for decorative interior paint had a widespread use in Europe and Sweden in the eighteenth century. In Sweden there were several different traditions and practices of using painted textiles to decorate walls. Decorating rooms on festive occasions with painted wall hangings was common practice amongst wealthy farmers in southern Sweden in the eighteenth-century. The valuable paintings were only hung on the walls temporarily, possibly to save them from smoke and soot, and are referred to as *bonadsmåleri* (Nyström 2012, p. 51). Painted canvasses permanently fastened to the walls became increasingly popular in wealthier homes as the rococo style was introduced in the mid eighteenth century. As wall decorations, the painted canvasses often replaced textiles (Fridell Anter & Wannfors 1997, p. 108). Noderman (1997) suggests using the term "wall painting" (*väggmåleri*) for paintings on canvas permanently fixed to the wall and not intended to be moved (Nodermann 1997, p. 149). Internationally the terms used for permanently fastened wall paintings on canvas supports vary. They are referred to as painted wall hangings, salon pieces or painted chambers. In many cases these paintings have been dismantled from their original location, for which they were created as part of a decorative interior scheme. Sometimes they are reconstructed in museums, and in other cases they are kept as isolated object (Vos et al. 2015, p. 99).

The rococo era in Sweden was initiated in 1732 with the completion of the interiors in the royal castle in Stockholm by the architect Hårleman. Hårleman, who had studied in France, employed French painters and carvers to decorate the interiors of the castle. This group of artists brought with them rococo influences. From Stockholm and the royal castle, the rococo influences spread to the rest of the country (Alm 1997, p. 28-29). Significant for rococo style interiors were walls with dados in the same height as the windowsills. Above the dados, there was stretched canvas framed with painted or carved rocaille ornated moldings. The canvasses were either painted in situ or in workshops, with oil being the prevailing paint medium. Popular motifs were flowers, ornaments and idyllic landscapes (Fridell Anter & Wannfors 1997, p. 108-114). Regarding the materials used, these canvas wall paintings would not differ much from canvas easel paintings, although the scale is often larger. An important difference is the fact that they are always an integrated part of the interior scheme of the room for which they were made, and cannot be considered individual objects (Grate 1997, p. 191).

2.2. Artists Material: Ageing and Deterioration

A traditional canvas painting is a layered structure of different materials. Traditionally the support is a linen canvas which is sized with an animal glue to make it more rigid and isolate the canvas from the paint. The ground is often a mix of either chalk (Calcium Carbonate $CaCO_3$) or gypsum ($CaSO_4 \cdot 2H_2O$) and an animal glue, such as rabbit skin glue. The ground can also be a white pigment, such as lead white, bound in oil (Stols-Witlox 2012, p. 162-168). On the ground are layers of paint, often multiple, consisting primarily of pigment and a binder. In canvas paintings the binder is often a drying oil, such as linseed oil. There may also be additions, like driers, which are often metal salts, and fillers. In many

cases there are also non-original materials present, added to the painting during conservation or restoration interventions (van Loon, Noble & Burnstock 2012, p. 214-217).

The ageing and deterioration of paintings are complex processes influenced by many factors. The composition of the paint, which pigments and binders are used and in what proportions, together with the layering of the paint and the painting technique, are considered factors inherent to the composition. Pigments have different properties, depending on their chemical constitution, and may be fading or changing colour when combined with certain binders or when exposed to light. Soap formation is another process that is considered inherent to the painting composition, even though external factors such as moisture enhance the reaction (van Loon, Noble & Burnstock 2012, p. 214). Other factors may be regarded as external to the painting, such as the painting's exposure to climatic variations and to human interactions and interventions.

2.2.1. Chemical alterations

The binders used in traditional canvas paintings are organic substances such as drying oils, and in some cases proteins as well. The chemical reactions involved in ageing and deterioration of these materials are free radical reactions, such as autoxidation, and ionic reactions (Mills & White 1994, p. 160). Free radicals are atoms or molecules with an unpaired valence electron, which make them highly reactive. Autoxidation of a drying oil is a free radical chain reaction, where oxygen from the air reacts with the unsaturated fatty acids of the oil (Berg 2002, p. 18). The activation energy to initiate the autoxidation can be radiant energy such as light or heat, or heat transferred from surrounding molecules by collisions. Initially the autoxidation makes the oil transform from a liquid to a rubbery solid by polymerisation and crosslinking of the polymers. The autoxidation reaction at the same time also causes small low molecular weight molecules to form. These small molecules are not a part of the three-dimensional network of crosslinked polymers, and are regarded as degradative for the oil film (Mills & White 1994, p. 39). Some of these molecules, like aldehydes, alcohols, ketones and acids are volatile and will leave the paint film by evaporation (Berg 2002, p. 50). Other molecules, less volatile but also not part of the polymer network, act as plasticizers in the paint. With time, the paint may lose some of these plasticizing components and become brittle (Sutherland 2003, p. 111). Some authors suggest this is part of the natural ageing process of the paint, whilst others argue that the loss of plasticizers is a consequence of a painting's exposure to heat or solvents (Michalski 1991, p. 225) (Erhardt, Tumosa & Mecklenburg 2005, p. 147).

The ionic reactions in an oil paint involve metal ions from inorganic pigments or dryers and carboxylic acids from the binding medium. The reactions can lead to the formation of metal soaps, which in some cases cause degradation phenomena such as brittleness, delamination, increased transparency and darkening of the paint, as well as efflorescence and aggregates of crystalline metal soaps (Burnstock 2019, p. 243, Keune & Boon 2007, p. 161). The metals most prone to form metal soaps are lead (Pb) and zinc (Zn), but soaps from copper (Cu) and potassium (K) have also been observed (Keune & Boon 2007, p. 161). The carboxylic acids can be formed by an autoxidation reaction pathway leading to scission of the fatty acid chains and subsequent oxidation of the formed aldehydes to carboxylic acids. The carboxylic acids can also be a product of hydrolysis of the ester bonds in the triglycerides (Hermans et al 2019, p. 50, p. 55). At this stage the ions and carboxylic acids can form an ionomer network that acts as crosslinks between the polymers in the dried oil. In this way the ionomer network can increase

the stability of an oil paint in which the polymer network is weakened from ageing (Hermans 2019, p.116). The ionomer network can remain stable for long periods of time, but if water molecules are present, the ester bonds can be further hydrolysed. If the carboxylic acid generated by the hydrolysis has a saturated fatty acid chain, a free fatty acid is formed. A free fatty acid can diffuse through the polymeric network. When the free fatty acid forms a bond with a metal ion, a metal soap is formed. Depending on the conditions, the metal soap will remain distributed through the paint film, or form crystalline aggregates (Hermans 2019, pp. 123-127). When the metal soap crystallizes it increases in volume, and in some cases the aggregates even protrude through the overlaying paint (Burnstock 2019, p. 250). The increase in volume may also be one reason why metal soaps are associated with paint delamination. The difference in volume between affected and unaffected paint layers may cause disruption and subsequent delamination (Helou-de La Grandiere, Le Hô & Mirambet 2008, p. 161). As the formation of metal soap progresses, pigment and binding medium is reacted away. The loss of both pigment and binding medium can be significant (Hermans 2019, p. 125). Less pigment reflecting the light, and more non-reflective material in the paint, increase the transparency of the paint layer. If the paint is a mix of for example lead white and carbon black, the paint will appear darker as the lead white is partly reacting away. If there is a dark underlaying paint, the increasing transparency of the overlaying paint may darken the visual appearance, as the underlaying paint becomes visible (Noble, van Loon & Boon, 2008).

Humidity is found to influence the degree of degradation due to metal soap formation. Water molecules can generate free fatty acids by hydrolysis of the ester bonds, as mentioned above, and could also change the polarity and charge of the pigment surface (Hermans et al. 2019, p. 55, Hermans 2019, p. 128). Temperature is another factor influencing the degree of degradation. Locally higher temperatures, for example by exposure to direct sunlight, has been found to promote lead soap formation (Keune et al. 2016). Availability of free fatty acids, for example from an adjacent ground layer, has also proven to enhance the formation of metal soaps (Noble, van Loon & Boon 2008).

2.2.2. Mechanical response to climatic variations

Among the factors influencing the deterioration of canvas paintings are the climatic conditions, the relative humidity (RH) and temperature in which the painting is kept. The properties of each material in the painting determines the impact that the climate has on the deterioration of the painting as a whole. According to Mecklenburg and Tumosa (1991) two properties are fundamental for a material's response to climatic variations. The first is the material's dimensional change as a response to variations in either RH or temperature, or a combination of the two. The other is the material's response to the stress rise in the material upon shrinking, that is the strain or deformation of the material. In a restrained material, like paint attached to a canvas, the strain often results in the material cracking (Mecklenburg & Tumosa 1991, p. 174). To understand a painting's response to climatic variations, the properties of each separate layer must be considered, as well as the interaction between the layers and between the layers and the support. The composition of each layer, for example the pigment- binder ratio, determines its properties. The materials' different responses to the climatic variations may cause disruption between layers, which can result in cracking and delamination of the paint layers (Hendrickx et al. 2016, p. 445-446).

A linen canvas' dimensional response to changes in RH is difficult to predict. With an increase in RH up to 80% the fabric may either shrink or expand, depending on previous treatments, fabric density or possibly the temperature. At between 80 % and 85 % RH the fabric shrinks both when the humidity is

increasing and decreasing (von Reden 2013). Rabbit skin glue, as well as sturgeon glue, absorbs water to an increase in volume approximately 3,5% between 0 % and 80 % RH (Mecklenburg 2005, p. 124). When mixed with chalk or gypsum in a gesso ground layer, the dimensional change of the rabbit skin glue does not have the same impact, because the chalk ratio is often high, around 90 % pigment volume concentration (PVC). An increase in PVC instead entails increased brittleness. The gesso ground layer is considered the most mechanically vulnerable layer in a traditional painting, due to its PVC-related brittleness (Michalski 1991, p. 225, p. 241). The stress and strain in the rabbit skin glue is much higher than in the paint layers, and therefore the sizing is considered to be responsible for a large part of the humidity related deterioration in canvas paintings. On the other hand, a continuous film of sizing on the back of a canvas has been found to protect the canvas from humidity, which can be beneficial for the painting as a whole (Mecklenburg & Tumosa 1991, p. 175, p. 178) (Hendrickx et al. 2016, p. 451-452). Hide glue and sturgeon glue both gradually loose strength in high RH and are significantly weakened at RH around 75% (Mecklenburg 2005, p. 134-135). The RH induced swelling of an oil bound paint is generally much less than the swelling of a glue, but varies greatly depending on with what pigment the oil is mixed. For example, a paint layer containing lead white and a paint layer containing burnt umber swells 0,18 % and 2,6 % respectively, when the relative humidity increases from 0 % to 95 %. Most swelling takes place in the range 70-90 % RH (Mecklenburg & Tumosa 1991, p. 174).

The traditional painting media, glues, oils, resins, are amorphous or semi amorphous polymers. The polymers can be said to be in either a rubbery or a glassy state. In a rubbery state they can stretch without breaking, while in a glassy state they easily break. The amorphous polymers are long and entangled, and when in a rubbery state the molecular vibrations allow the polymer network to stretch without breaking. When lowering the temperature, the molecular vibrations decrease, and the material becomes brittle or glassy (Michalski 1991, p. 224). For an oil paint the transition from a rubbery to a glassy state takes place at temperatures from -10°C to -20°C (Mecklenburg 2005, p. 139). Variations in temperature also change the material dimensionally, even though the dimensional changes caused by temperature are much less than the dimensional changes caused by variations in relative humidity (Mecklenburg & Tumosa 1991, p. 188).

To minimize climatically induced deterioration, several standards have been established that specify what is regarded as a safe climate for museum objects and historic houses. Some examples of standards are the guidelines by Thomson (1978) in his book *The museum Environment*, the standards by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the European standard EN15757:2010. Most standards recommend an RH between 40-60% with short term fluctuations no more that 10% (Bratasz 2013, pp. 13-17). An object acclimatizes to its surroundings, and it is always a risk to change the climatic conditions. Even if the object is moved from a climate outside of the recommended RH range, to a supposed safe climate, the change imposes a risk. This is taken into account in the more recent standards, like ASHRAE and EN15757:2020. In these standards, the RH is not set to a certain percentage, instead the recommended RH is the *historic yearly average*. The safe range of seasonal and short-term variations are based on this RH (Bratasz 2013, pp. 14-16).

3. ARCHIVAL RESEARCH

Archival research is carried out with the purpose of tracking the treatment history of the paintings as well as the progression of deterioration over time. The archival records of the von Echstedt manor at the Värmland County Museum are researched with this purpose. Conservation treatments carried out during the last thirty years are also discussed with the museum's paintings conservator.

3.1. Restoration 1953-57

After acquiring the von Echstedt manor in 1939 *Värmlands museum* initiated a restoration of the buildings. The most urgent restorations of the roof and masonry were carried out before the project was halted due to the second world war. The restoration started again in 1955 (Hallén 2012, p. 119). In 1953, a proposal for restoration of the von Echstedt manor was established by the architect Ludvig Mattson on the request of *Värmlands museum*. In the section detailing the restoration of the Green Chamber, the proposal says that after the wallpapers are carefully removed to reveal the original paintings, the paintings should be carefully cleaned and restored by an experienced professional (Vm Byggnadsminnen 28 von Echstedtska gården 6). In 1955 Mattson writes about the restoration of the wall paintings in his diary, though not specifying in which room. He writes that, when visiting the von Echstedt manor on June 14th, 1955, the painters Åkerblom and Sjöquist were working on restoring the walls, and *beautiful paintings were emerging* (Vm Byggnadsminnen 28 von Echstedtska gården 6). When the restoration finishes in 1957, a protocol is written by the director of *Värmlands museum*, Gösta von Schoultz. He writes that before the restoration the Green Chamber wall paintings were covered with several layers of wallpapers, and that they were very damaged, especially on the west exterior wall (Vm Byggnadsminnen 28 von Echstedtska gården 4). The paintings on the west wall were replaced by new canvasses on which only the colors and basic layout of the originals were painted. During the restoration an opening in the wall facing the appendix north of the Green Chamber was closed. New canvas was put up on this wall as well, painted like the west wall canvas. The strip lining, of which the fabric is visible around the edges of the canvas of the original wall paintings, was most likely done during the 1955 restoration, since it has the retouch paint from this period. This indicates that the canvasses were brought down from the walls during the restoration and re-stretched when re-mounted on the walls.

In the above-mentioned protocol by von Schoultz (1957), there are four photographs showing the wall paintings in the Green Chamber during and after the restoration 1955. One photograph shows the left part of the south wall that today has the most severe deterioration. The photograph was taken after the wallpaper was removed, but before the losses were retouched (figure 5 below). Three patterns can be distinguished in how the losses are distributed on this part of the south wall. There are losses forming horizontal lines that seem to correspond with the edges of the underlaying timber. The patterns of losses in a vertical direction seem to be of two kinds. There are the losses on, and in the proximity of, the seam where the stretches of canvas are stitched together. The other pattern of vertically oriented losses is seemingly not corresponding with the support structure. These areas are less defined and approximately 50 cm apart, which is the standard width of industrially produced wallpapers from the 1830s and onwards (Broström & Stavenow-Hidemark 2004, p. 268). One cannot know for sure what caused the losses seen in figure 5, or what the condition of the wall painting was when the first wallpaper was put up. Anyhow, the losses supposedly corresponding with the wallpaper edges, suggest that the losses may to a large extent have to do with the process of repeated wallpapering and the removal of the same.

Wallpapers are traditionally pasted with the edges overlapping. The overlap creates a ridge that may result in extra pressure on the underlaying painting, for example when the glue paste for subsequent wallpapers is applied, or upon the stretching during the drying and shrinking of the subsequent wallpapers. The area of the overlap, like the top and bottom of the wallpaper, is also an area where there is often extra paste applied to ensure fastening the edges. The other losses mentioned, corresponding to the canvas seams and the timber edges, are also areas that are exposed to extra pressure because of ridges or edges from the backside of the canvas.

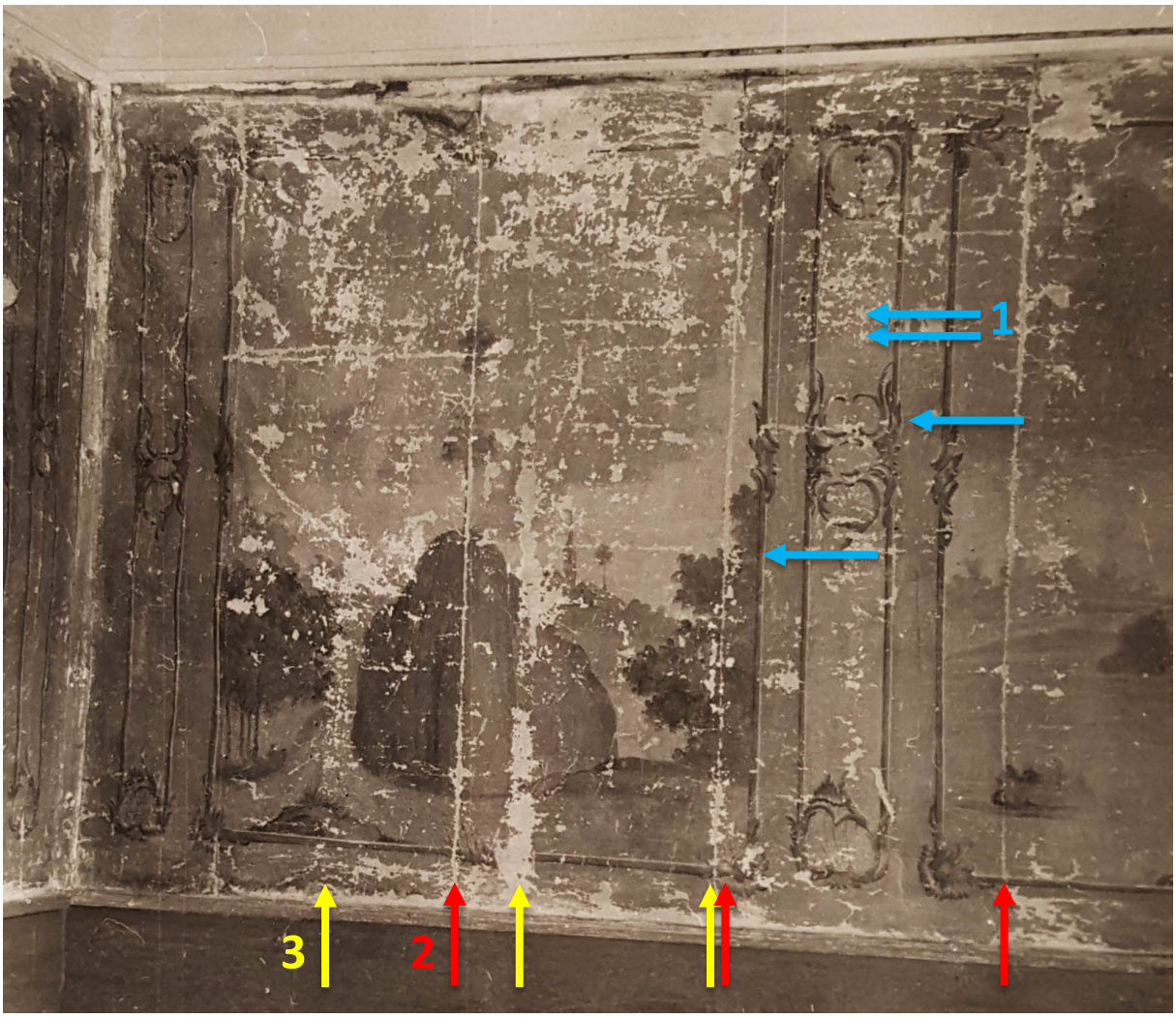


Figure 5. Photograph of the left part of the wall painting on the south wall during restoration 1955. Three different patterns can be recognized in the losses: 1. Horizontal lines probably corresponding to edges of the timber behind the canvas, 2. Losses on canvas seams, 3. Vertical lines approx. 50 cm apart. Photographer Gösta von Schoultz, copyright Värmlands museum. Photograph cropped by the author.

3.2. Treatment 1992

In 1992 the Green Chamber wall paintings were undergoing conservation treatment by the conservation studio RAK. According to the condition assessment stated in the conservation report, the canvas on the south wall was bulging, and on both the south and east walls the paint was delaminating. In the condition assessment it also says that the retouches from 1955 gave the paintings a patchy and flat appearance. The paint on the south and east wall paintings was consolidated with sturgeon glue 5% with a little alcohol, using a portable vertical low-pressure vacuum table. The treatment was done in situ. Retouches were done using watercolours (Windsor & Newton) (VM Byggnadsminnen 28 von Echstedtska gården 6, RAK 1992, p. 19-22).

3.3. Treatment late 1990s

1998 or 1999 the wall painting on the south wall was treated again. In the areas that were consolidated in 1992 the paint was once again delaminating. The canvas was demounted from the south wall and transported to the museum's conservation studio. In the studio the whole painting was consolidated with sturgeon glue using a Mitka low pressure vacuum table. Due to the size of the painting, the consolidation was done in one area at a time (source 1). Unfortunately, the conservation report from this treatment seems to be lost. According to the museums conservator the treatment seemed successful at first. The paint was relaxed and re-adhered to the ground layer. The painting was brought back to the von Echstedt manor and once again mounted on the south wall. The canvas was relatively flat after being re-mounted. The painting seemed to be in good condition for approximately four years before the paint gradually started to delaminate from the ground layer once again. Since the treatment 1998-99 the museum's conservator has done local treatment in situ to prevent paint loss in the most urgent areas. The treatment was carried out using sturgeon glue and a heat spatula. On one occasion beeswax was used to consolidate the paint. The beeswax was applied warm with a brush (source 1). In 2016 the paint layer on the left side of the painting on the south wall was delaminating to such an extent that it was considered too fragile to treat locally or to leave unprotected in the museum. The area was covered with a facing of Japanese paper adhered with a low percentage gelatin solution for protection until a treatment plan is established (source 1).

4. ANALYSIS METHODS

4.1. Optical Microscopy

Optical microscopes are used for studying surface features and samples under magnification. In painting conservation optical microscopes are used for identification of for example fibers, minerals and paint. Optical microscopy is also called light microscopy, since the variety of optical microscopes all use light in different ways, as reflected, transmitted and polarized (Stuart 2017, p. 81). In cross-section microscopy one studies the layering of materials present on a painting. The sequencing of preparatory layers, paints and varnishes provides an insight into the painting technique and materials used. Non original materials, such as retouch paint and grime, are also sources of information about the history of the painting (Buck et. al 2012, p. 326).

In this study the surfaces of the wall paintings are examined in situ with a portable monocular usb-microscope. The microscope used is a Dino-Lite Edge Digital Microscope with led light. Areas of interest are photographed with the Dinolite microscope using the software Dinoxcope on a usb-connected laptop. Cross-sections are made from the collected paint samples. The cross-sections are embedded in light curing resin Technovit, cured in a Technotray blue light oven, and water polished. The cross sections are examined and documented in 10x and 20x magnification using a Nikon Optihot microscope with reflected light and attached digital camera. For canvas fiber identification a dispersed fiber sample is mounted on a glass slide with a drop of glycerol and a coverslip on top. The sample is studied in transmitted light under the Nikon Optihot microscope and photographed with a mobile camera through the ocular lens.

4.2. Ultraviolet Fluorescence Imaging

Ultraviolet Fluorescence is the light emitted by a material exposed to ultraviolet (UV) radiation. When a material is radiated with UV, some materials absorb the radiation. The absorbed radiation excites electrons to higher energy levels. As the electrons relax back to lower energy levels, they emit photons, radiation in the visible spectrum. The color of the fluorescence is characteristic of the material. Many materials used in paintings are fluorescent, and examination with UV light is commonly practiced. Varnishes are often strongly fluorescent, making underlaying materials difficult to distinguish. When photographing UV-fluorescence a filter is commonly put on the camera to filter out the UV radiation (Stuart 2007, pp. 75-76).

In this study the paintings are examined in UV-light to distinguish where different materials are present on the painting by their fluorescence. Photographs are taken of the UV fluorescence for enabling comparison with visible light photographs of the same areas. The UV-light source used is a UVP Mineralight UVG-54 handheld short-wave UV-lamp. The windows in the room are completely blinded to avoid interference from daylight. Photographs are taken with a Fujifilm X100 digital camera on a tripod with exposure times around 30 seconds. No filter is used on the camera. Since the scale of the

painting is large, the handheld UV-lamp is moved around during the exposure time to radiate the photographed area evenly.

4.3. Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy

In Scanning Electron Microscopy (SEM) the sample is scanned with a focused electron beam in vacuum to create high magnification images with great depth of field, and to provide information on the elemental composition of the sample. When the electron beam hits the atoms in the sample, the electrons in the beam interact with the electrons in the atoms of the target. From this interaction different signals are produced, backscattered electrons, secondary electrons and X-ray fluorescence. The backscattered electrons are electrons from the beam that are repelled by the electrons in the sample. These electrons are scattered back without losing much energy. The electrons are detected by the instrument, and a Backscattered Electron (BSE) image of the sample is created. In the BSE-image the electron density of the sample is visualized. Elements with high atomic numbers appear bright in the BSE-image, while elements with low atomic numbers appear darker (Stuart 2007, p. 91-95). The Secondary Electrons (SE) are weakly bound electrons in the outer orbitals of the atoms that are ionized by the energy of the electron beam. These electrons have a lower energy than the backscattered electrons. The electrons are detected, and SE-images are created that show the topography of the sample (Goldstein 2018, p. 30). The electron beam also excites strongly bound electrons in the inner orbitals of the atoms in the sample. The rearrangement of the electrons leaves voids where electrons are missing in the inner shells. Electrons from orbits with higher energy fall into these voids. When doing so, they emit photons in the form of x-rays. The emitted x-rays are corresponding to the difference in energy of the orbits and are characteristic for each element. The x-rays are detected by an energy dispersive x-ray spectrometer (EDS), and plotted in a spectrum (Goldstein 2018, 40).

In this study SEM-EDS is used primarily for pigment identification and pigment distribution in the paint layers. The elemental composition of the paint layers provides an indication on what pigments are present in the paint (see chapter 5.2 *Pigment Identification*). The samples analyzed are two resin embedded cross sections that together have the identified paints of the painting represented. The samples are carbon coated prior to analysis in order to make them conductive. Because of the carbon coating, the element Carbon (C) will not be detected in the EDS-analysis. The instrument used is a Hitachi S-3400N Scanning Electron Microscope with the settings 10kV, Probe Current 40 and Emission ca 100 uA. For the EDS-analysis, the instrument's default spectra are used as references. The EDS result is regarded as qualitative rather than quantitative, although an approximate estimation of the ratio of the elements present can be made from the results (Microscopy Australia 2021). The SEM-microscopy is performed by principal research engineer Delia Rösel from the Department of Earth Sciences at the University of Gothenburg.

4.4. Fourier Transform Infrared Spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) uses infrared radiation to determine a material's molecular composition. When interacting with the material, the infrared radiation can be absorbed and cause the chemical bonds in the molecules to vibrate. The radiation is in the mid infrared region from

4000 to 500 wavenumbers (cm^{-1}). The different kinds of bonds absorb specific frequencies of the infrared radiation. The functional groups absorb radiation in the group frequency range, 4000-1300 cm^{-1}, and single bonds, as well as skeletal vibrations, absorb radiation in the so-called fingerprint region, 1300-500 cm^{-1} (Derrick, Stulik & Landry 1999, p. 13-15). A functional group absorbs radiation in the same range regardless of the structure of the rest of the molecule. For example, the most significant absorption of the carbonyl bonds (C=O) is their stretching vibration between 1800-1600 cm^{-1} independent on which molecule they are part of (Smith 1999, p. 21). The absorption in the fingerprint region is unique for each individual compound and can be compared with reference spectra for identification (Derrick, Stulik & Landry 1999, p. 94). The remaining radiation, not absorbed by the material, is detected and plotted in a spectrum. In the spectrum, frequency bands absorbed by the material are shown as upward pointing peaks if the spectrum is in absorbance, and as downward pointing peaks if the spectrum is in transmittance (Smith 2011, p. 5). By reading the spectrum one can identify compounds present in the material by the presence or absence of functional groups, and by comparison with existing spectra of known materials. In a composite material, all frequencies absorbed by the compounds present are shown in the same spectrum. Peaks may overlap or obscure, making the spectrum difficult to read (Smith 1999, p. 25). In the case of proteins, there are few differences in the spectra from the different kinds of proteins, making it difficult to differentiate between them. For exact identification of proteins other techniques such as liquid or gas chromatography are required (Derrick, Stulik & Landry 1999, p. 108).

In this study FTIR- analysis is done with the purpose of identifying organic components of the painting, such as binders and varnish, and to some extent also inorganic pigment compounds. The FTIR-analysis is in this case done with an Attenuated Total Reflectance (ATR)- application. In FTIR-ATR a beam of infrared radiation travels through a crystal of high refractive index, for example a diamond. The sample is clamped to obtain optimal surface contact with the crystal. When the beam is reflected off the interior crystal surface in contact with the sample, some frequencies of the infrared radiation are absorbed by the material, as described above. The remaining radiation is detected when leaving the crystal (Smith 2011, p. 129). Analysis is in this study done with an Alpha Brooker II FTIR- instrument with a diamond crystal Bruker Platinum ATR application and the software OPUS (Bruker 2021). The number of scans is set to 50, the resolution is 4 cm^{-1} and the range is 4000 – 400 cm^{-1}. The acquired spectra are plotted in absorbance units. The samples are analyzed without further preparation, except for the sample from the 1950s retouch paint that had an unclear spectrum in the first acquisition. This sample is wetted with acetone and collected on the crystal. After the acetone is evaporated the sample is analyzed as above. The reference spectra used for comparison are from the spectral database of the Infrared and Raman Users Group (IRUG), which is specialized in conservation materials (IRUG 2021).

5. INVESTIGATION

5.1. Green Chamber wall paintings: Structure, Technique and Condition

The canvas support consists of stretches of canvas sewn together from the back. The width of the canvas stretches is approximately 60 cm, except for the stretches on the sides which are narrower to make the whole fabric fit on the wall. The canvas on the south wall measures in total 188 x 360 cm and the canvas on the east wall 163 x 188 cm. Along the edges the canvas is strip-lined with a fabric approximately 12 cm wide. The strip lining is partially visible along the edges of the canvas on both walls. The original canvas is a plain weave with approximately 27 threads per inch in the warp and 21 threads per inch in the weft. The thickness of the weft threads varies, while the warp threads have a more even thickness. Fibres from the canvas are studied under microscope for identification. The fibres show the characteristics of a flax (linen) fibre, with multiple fibres in a bundle and nodes visible across the fibre bundles (fig. 6) (CCI 2010, p. 3). The canvas is fastened to the wall with nails around the edges. The nails are approximately 85 mm apart and are visible above the south wall where the cornice is missing. The canvas seems to be nailed directly on the timber wall with no other supporting structure. The stretches of canvas used for the wall paintings in the other rooms seem to have a similar width and weave pattern as the canvas in the Green Chamber.

Figure 6. A canvas fiber under microscope with transmitted light. Nodes can be seen across the bundles of fibers. The fabric is identified as linen.

Figure 7. Detail of the wall painting on the south wall in raking light. The area most affected with delamination is also the area where canvas has the most deformations.

The canvas is loosely stretched and deformed. In the lower corners there are slanting draped bulges. Most deformation in other areas are in a vertical direction. The whole canvas is affected, although the

left side of the painting on the south wall has the most prominent deformations (fig. 7). There are a few holes, no larger than 2 cm in diameter, where the edges of the fabric are worn. In the upper edge of the canvas on the south wall, the nail holes from a previous attachment are visible in between the present nails. In some places the seams attaching the separate stretches of canvas are open, and the stitching thread is missing.

The motif is painted using a limited number of paints. The layering of the paints is visualized in cross sections of paint-layers from different areas of the painting, see appendix 1 for location (fig. 8-10). On top of the ground layer is a thinly painted light brown imprimatura. The same brown seems to have been used to sketch the motif. The brown is visible in between brushstrokes and on details such as the hills in the background and in the light fields of the frame (fig. 12). On top of the brown are hues of green, from very light to very dark. The landscapes are for a great part painted wet in wet which is evident in usb-micrographs and also in some of the cross sections (fig. 8, fig. 11). The marbled wet in wet blending of the paints concerns the different hues of green, as well as the greens together with the light paint used for skies and water. The paint used for light details, as well as for the lines and ornaments surrounding the landscapes, does not blend with the underlaying paint, and seems to be applied on dry paint. A cross section made from a sample from the surrounding ornaments show more distinct layers (fig. 9). The pure dark green, with no white mixed in, has a glaze-like appearance (fig. 13). Large sized pigment particles are visible both on the paint surface and in the cross sections of the paint layers (fig. 9, fig. 10, fig. 12).

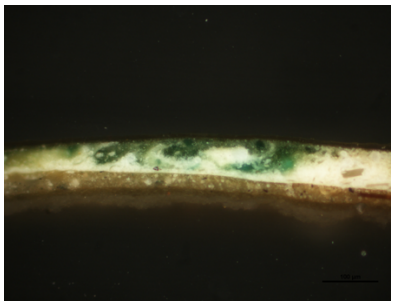


Figure 8. Cross section of sample 6. Dark green and white painted wet in wet on top of the brown imprimatura

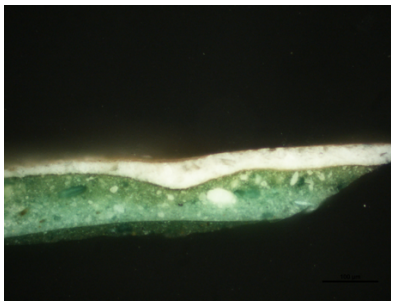


Figure 9. Cross section of sample 5. The white paint used for details is seen on top of two layers of green

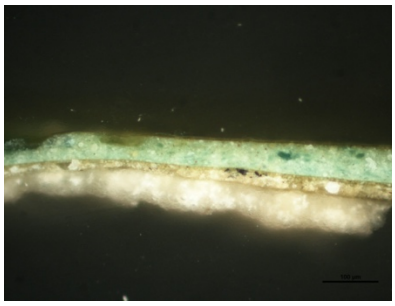


Figure 10. Cross section of sample 1. The ground layer, the imprimatura and a green paint is visible

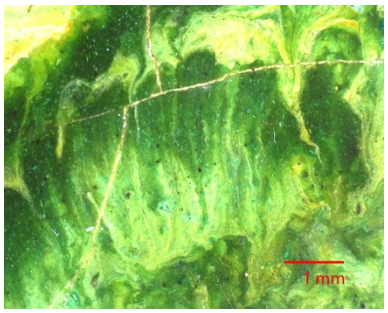


Figure 11. Micrograph of area 14. The marbled effect of wet in wet painting of dark and light green paint.

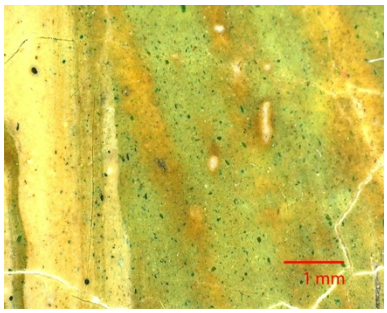


Figure 12. Micrograph of area 10. The brown imprimatura is visible between brushstrokes and large pigment particles are seen on the paint surface.

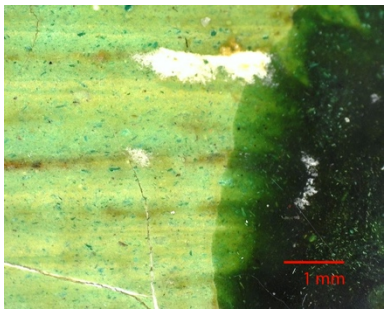


Figure 13. Micrograph of area 14. The dark green paint appears transparent.

A network of cracks is present all over the original paint layers on the two canvasses. The cracks form ridges that are seen in the raking light photographs (fig. 14). For the most part the cracked paint is well adhered to the canvas, but in some places the paint layers are delaminating from the ground layer. The area most affected by delamination of the paint layers from the ground layer, is the earlier mentioned area situated to the left on the south wall. This area has for the most part protective facing of Japanese paper, but the delamination phenomena can be studied in adjacent areas without facing (fig. 15). The area most affected by delamination is also the area where the paint is most significantly darkened. The light sky above the church and hill is seemingly the area most affected by the darkening (fig. 16). An unvarnished area on the south-east wall appears to be one of the best-preserved areas of the painting. The paint in this area has a fine craquelure, but the cracks are not forming ridges as in other areas (fig. 18, fig. 19). It does not have the problem with delamination seen in other areas of the painting.

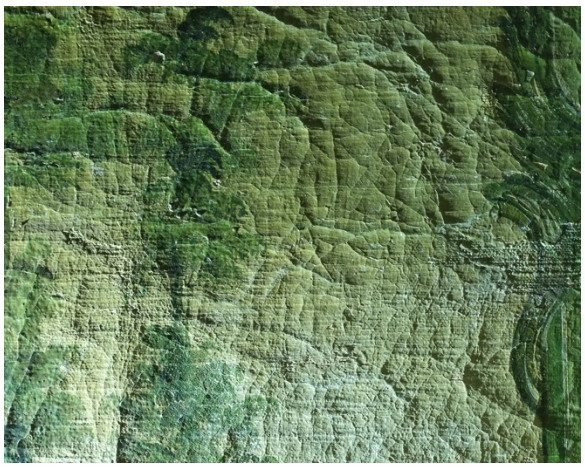


Figure 14. Detail in raking light of an area by the two trees in the right landscape on the south wall. The pattern of cracks is visible.

Figure 15. Micrograph of area 3. The paint layers are delaminating from the ground layer.

There are areas where both the original ground and paint are missing (appendix 2, p. 50). In the retouches in these areas the structure of the canvas is visible, indicating that the retouch is painted on bare canvas or on a very thin ground layer. These retouches correlate with the losses seen in the pre-restoration photograph from 1955, and it is concluded that the retouches originate from the 1955 restoration (fig. 5, p. 20). There are also later retouches visible on top of some of the 1950s retouches. These retouches appear dark in UV-light and are most likely the watercolor retouches mentioned in the conservation report from 1992 (fig. 17). The 1950s retouches seem to be varnished with the same varnish as the rest of the paintings. The reconstructed paintings on the west wall also seem to have the same varnish. Nor the retouches or the reconstructed wall paintings show signs of cracking or delamination.

The varnish is applied on most of the painted surfaces. The varnish is unevenly applied with visible brushstrokes and has a greenish fluorescence in UV-light (appendix 2, p. 49). Fluorescence of the varnish is also seen on the painted wooden moldings surrounding the paintings. The application pattern and the UV-fluorescence are similar all over the painted surfaces, which indicates that the walls probably were varnished in one application using the same varnish. Since this varnish is also visible on the retouches on bare canvas dated to the 1950s, it is likely that the varnish was applied as a final step in the 1950s restoration of the paintings. The varnish is darkened and appears brown where thickly applied. The earlier mentioned unvarnished area on the painting on the east wall measures approximately 25 x

50 cm. It is not clear if this area was left unvarnished in the 1950s intervention, or if the varnish in this area has been removed at a later stage. No documentation on varnish removal was found in the archives.

Figure 16. Detail of the left landscape on the south wall in normal light. Retouches from the 1950s are seen as light areas around the church tower and along the seam in the canvas to the right. Above the church tower and in the top right corner some of the darkened original paint is visible.

Figure 17. The same area in UV-light. Thin lines of a watercolor retouch, probably from the 1992 intervention, are visible on top of some of the 1950s retouches. The watercolor appears black in UV-light. Wax used for consolidation is visible as well and appear light blueish, for example in the crown of the tree beside the church.

Figure 18. Detail of an unvarnished area in the bottom left corner of the wall painting on the east wall. The unvarnished green paint appears a little lighter and brighter.

Figure 19. The unvarnished area in UV-light. The unvarnished area appears dark. A pattern of very fine cracks is seen as white lines.

5.2. Pigment Identification

The identification of pigments relies in this study on both the results of SEM-EDX and FTIR. The elements present are identified with SEM-EDX, while the pigments' molecular bonds in some cases are identified with FTIR. In the two cross sections analyzed with SEM-EDX the different paint layers described in the previous chapter are represented. In cross-section 7.1. there is the ground layer, the light brown imprimatura, one light green paint and the dark green glaze-like paint (fig. 20). Cross section 5.1. lacks the ground layer and the imprimatura but contains the white top paint layer used for details, as well as two layers of green paint (fig. 25). Micrographs of the sites of sampling, and the locations, are found in Appendix 1 (pp. 46-48).

The ground layer, present in sample 7.1., is analysed with EDX in 34 different spots. The spots are distributed along three lines across the sample, and in one more area (appendix 4, p. 56). The prevailing elements detected in the ground layer are oxygen (O) and calcium (Ca), indicating that the main constituent is most probably chalk, calcium carbonate ($CaCO_3$). FTIR analysis of a sample of the ground layer also shows the presence of calcium carbonate ($CaCO_3$) with sharp peaks at wavenumbers 711, 870 and 1794 cm^{-1} (Derrick, Stulik & Landry 1999, p. 117) (IRUG 2021, spectrum IMP00115). In most of the spots analysed, there are small amounts of silicon (Si), and in some spots also magnesium (Mg) and aluminium (Al), all of which can be attributed to common impurities of silt and clay found in natural chalk (Gettens, West Fitzhugh & Feller 1993, p. 203, p. 210). In the bright white material seen underneath the ground layer in figure 20, the elements listed above are present, as well as zinc (Zi) and titanium (Ti). Zink oxide and titanium dioxide were not commercially available until 1842 and 1916 respectively, which is too recent for the pigments to be a part of the painting's original composition (Kühn 1986, p. 171) (Eastaugh 2008, p. 412, p. 370). The white material is most likely a fragment of the ground used for the adjacent 1950s retouch.

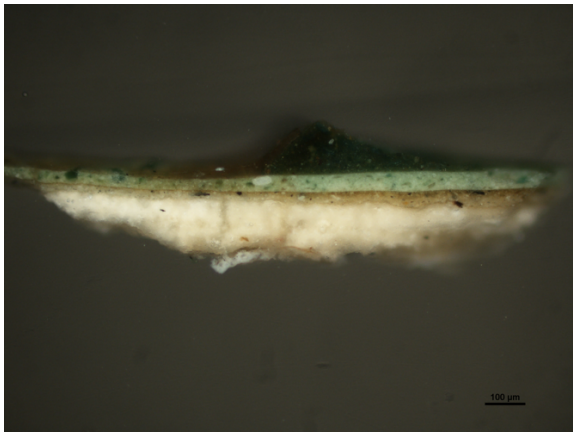


Figure 20. Cross section of sample 7 named 7.1. The ground, the imprimatura, a light green paint and the dark green paint can be seen in the cross section.

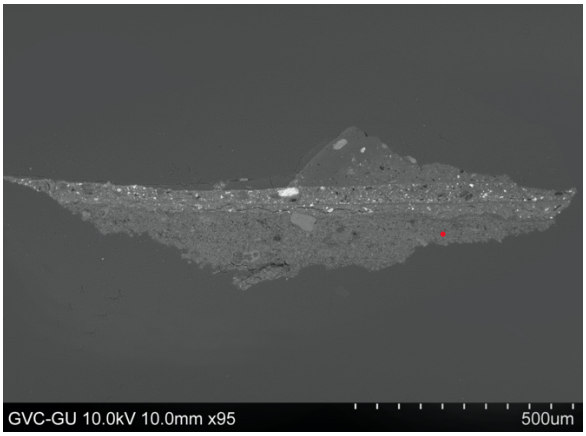
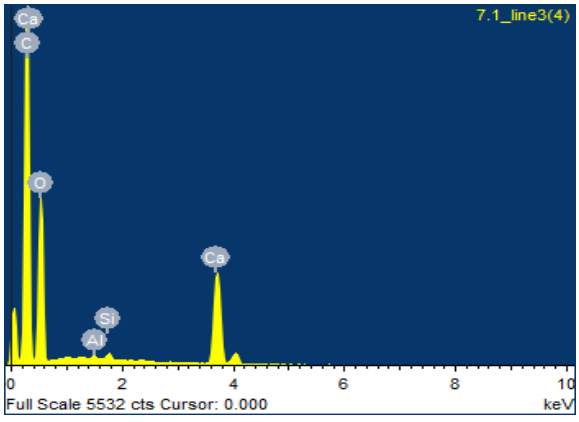


Figure 21. BSE- image of cross section 7.1. One of the spots analysed with SEM-EDS is marked with a red dot.



Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
O K	41.53	1.0844	38.31	0.36	75.70
Al K	0.27	1.0827	0.25	0.04	0.30
Si K	0.63	1.1422	0.56	0.05	0.63
Ca K	29.99	1.0120	29.64	0.27	23.38
Totals			68.75		

Figure 22. The elements detected with SEM-EDS in the spot marked with a red dot in figure 21 are typical for most spots analysed in the ground layer and indicate the pigment used is chalk ($CaCO_3$).

In the light brown imprimatura, iron (Fe) is detected, indicating that the brown pigment may be an ochre (Eastaugh 2008, p. 407). The elements indicating chalk are found in this layer as well. Chalk was

probably used as a filler in this paint, but the same elements can also be attributed to minor components of chalk and clay in the ochre pigment (Eastaugh 2008, p. 905). There is also lead (Pb) in the paint, most likely from lead white (basic lead carbonate ($2PbCO_3.Pb(OH)_2$)). Lead white was the dominating white pigment for oil paint before the 19th century (Gettens, Kühn & Chase 1993, p. 69). One of the black particles in the paint layer is analyzed and does not show any elements associated with black pigments. Therefore it is very likely that the black pigment is a commonly used carbon black, since carbon (C) is not detected by EDS in a carbon coated sample.

In the light green layer in cross section 7.1., as well as in the light green layer in cross section 5.1., the predominant elements are oxygen (O), lead (Pb) and copper (Cu). The distribution of the elements corresponds with the visible colors of the paints. In whiter areas, or particles, there is more lead and in greener areas, or particles, the dominating element, apart from oxygen, is copper (Cu). The lead containing pigment in the white paint is most likely lead white ($2PbCO_3.Pb(OH)_2$)). In the copper containing green paint, the green pigment is presumably one of the various green copper pigments. In the BSE-images, a fibrous structure can be seen in some of the larger green pigment particles. The fibrous structure, together with the angular form of the pigment particles, are strong indications that the green pigment is a natural malachite (basic copper carbonate ($CuCO_3.Cu(OH)_2$) (Gettens & West Fitzhugh 1993, p. 187) (fig. 23, fig. 24). Blue pigment particles, visible on the surface in some green areas of the painting, are likely to be azurite ($2CuCO_3.Cu(OH)_2$), which often is found together with the mineral malachite (Scott 2002, p. 102) (fig. 24). In the dark green paint, the top paint layer in cross section 7.1., copper is detected throughout the paint layer, and also some iron and lead. As seen in the BSE-image (fig. 21), the area to the left in the dark green paint lacks visible pigment particles, apart from the large grey particle. Visually the paint appears transparent (fig. 13). It is possible that the pigment used is verdigris (copper acetate ($Cu(CH_3COO)_2$)). When verdigris is mixed with oil it has a glazing effect. With time, the pigment reacts with the oil-medium to form transparent copper salts of fatty acids, a carboxylate, also referred to as copper oleate (Kühn 1993, p. 135, p.149). FTIR analysis of a sample of the dark green glaze seems to confirm the presence of a carboxylate. The FTIR spectrum has the two intense bands that are characteristic for the asymmetric and symmetric stretching of the CO_2-bonds in a carboxylate, at wavenumbers 1560 and 1406 respectively (Smith 1999, p. 103).

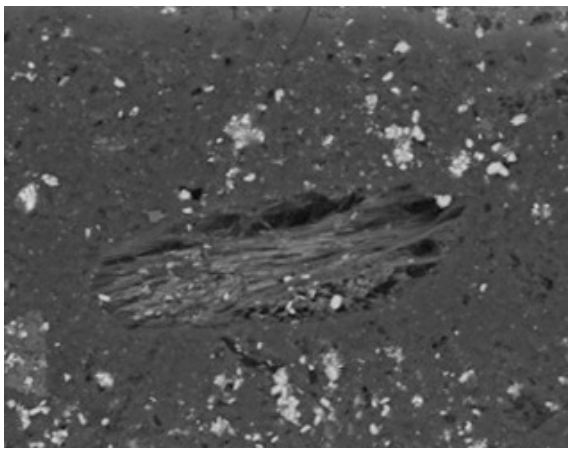


Figure 23. A green pigment particle in BSE-image of cross section 5.1. The fibrous structure is characteristic of malachite (CuCO3.Cu(OH)2).

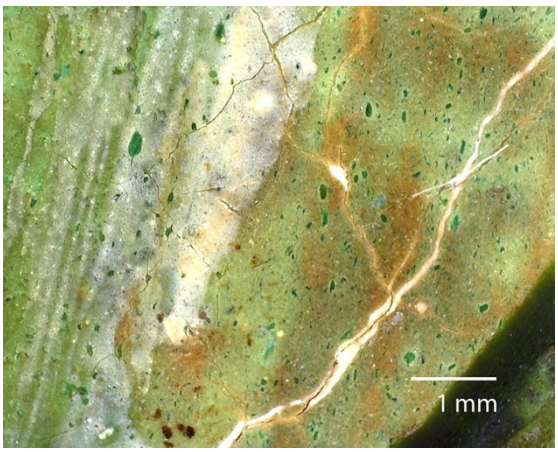


Figure 24. Micrograph of area 15. Pigment particles visible on the surface of the painting have the characteristic angular shape of malachite. Blue particles are visible as well.

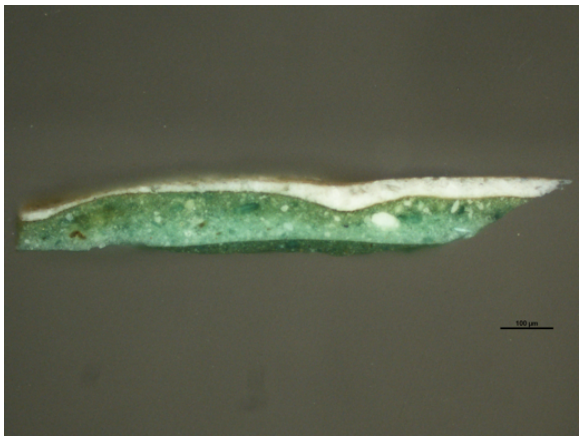


Figure 25. Cross section from sample 5 (5.1.). Two layers of green paint and the white paint used for details can be seen in the cross section.

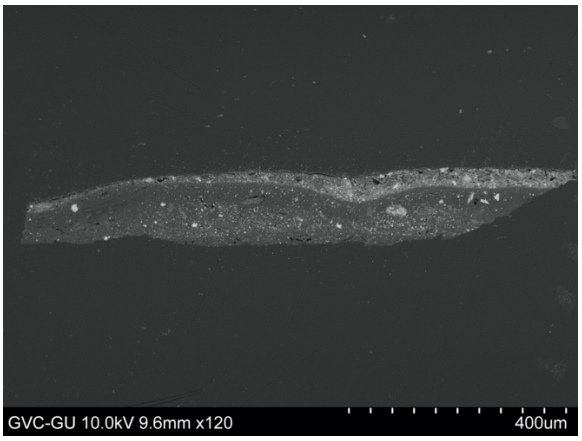


Figure 26. BSE image of cross section 5.1. Heavy elements like lead appear bright in the BSE-image.

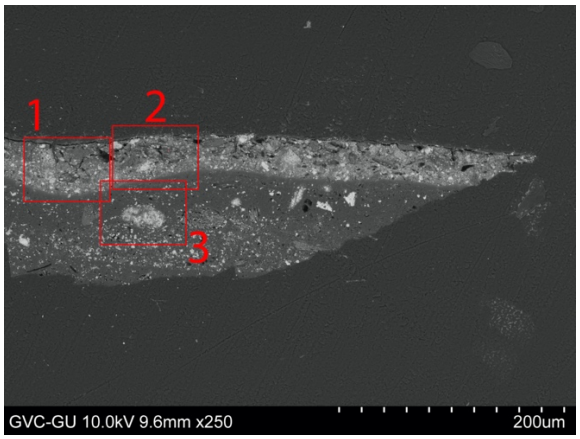


Figure 27. Areas in the BSE- image of cross section 5.1. where signs of lead soap formation are detected. See close-ups in the following images.

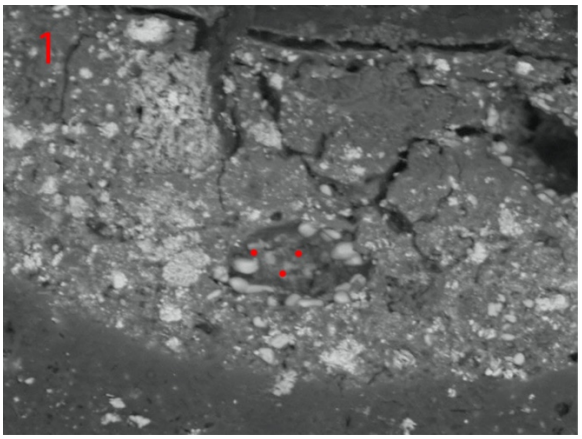


Figure 28. The grey area where the red dots are is possibly an aggregate of lead soap. The red dots mark spots for EDS-analysis. Lead and oxygen the are elements detected.

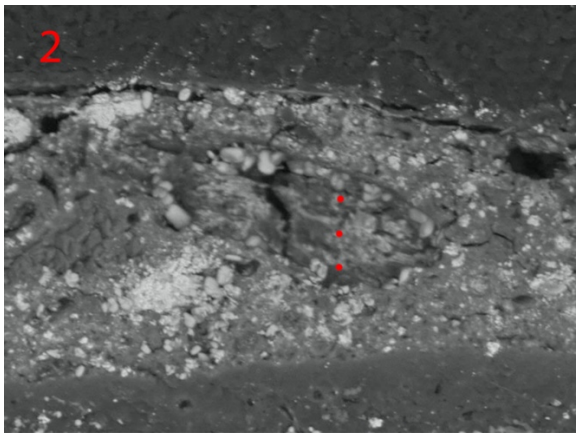


Figure 29. Grey amorphous area where the red dots are is possibly an aggregate of lead soap. The red dots mark spots for EDS-analysis. Lead and oxygen the are elements detected.

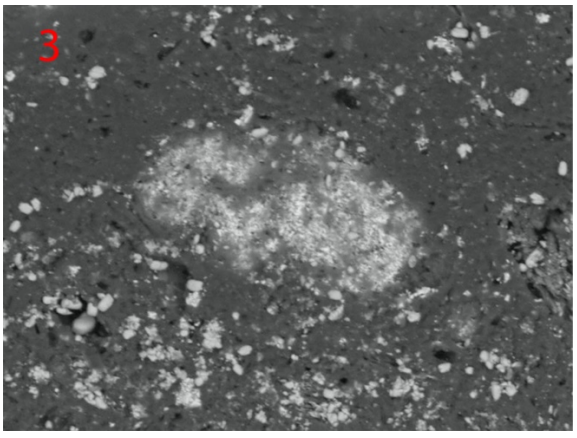


Figure 30. A big lead white particle in cross section 5.1. The undefined, disintegrated edges of the pigment particle may be a sign that metal ions are migrating from the pigment surface to form lead soap.

The sample for cross section 5.1. is taken from the painted border surrounding the landscapes. The cross section contains the white paint used for lines and decorative elements in these areas. The result from EDX shows there is lead (Pb) and oxygen (O) present, and in most spots also calcium (Ca). This indicates that the pigment in the white paint is lead white ($2PbCO_3.Pb(OH)_2$)) with chalk ($CaCO_3$) as a filler. In some spots silicon (Si), magnesium (Mg) and aluminum (Al) are also detected, most likely also from the chalk (Gettens, West Fitzhugh & Feller 1993, p. 203, p. 210).

In BSE-images of cross sections that contain lead white, the lead white pigment is normally seen as bright, coarse and well-defined particles in varying sizes (Keune, van Loon & Boon 2011). In cross section 5.1., most of the lead white pigment particles seem disintegrated and without defined edges (fig. 30). The undefined edges may be a sign that the lead white pigment has reacted with the binding media to form lead soap. During lead soap formation, lead ions migrate from the pigment surface to the binding medium, and the surfaces of the pigment particles become disintegrated (Keuene & Boon 2007, p. 164). Other features that may indicate there is lead soap present in the paint layers are the amorphous grey areas seen in the BSE-images (fig. 28, fig. 29). These areas have both the visual and elemental characteristics of lead soap aggregates. The areas are inhomogeneous and grey, and lead and oxygen are the only elements detected by EDX in these areas (the samples are carbon-coated, hence no carbon is detected) (appendix 4, p. 54-55) (Keuene & Boon 2007) (Keune, van Loon & Boon 2011).

5.3. Binder and Varnish Identification

FTIR analysis of sample 3 from the ground layer indicates that both oil and protein are present in the sample. The amide groups in proteins absorb infrared radiation in the region 1650-1450 cm^{-1}. In the spectrum acquired from the analysis of the ground layer there are peaks in this area, although not very sharp and distinct. There are also two sharp peaks significant for oil in the hydrocarbon stretching area at 2917 cm^{-1} and 2849 cm^{-1}. The third peak important for identifying oil can be seen in the acquired spectrum at around 1740 cm^{-1}, but it is partly obscured by other peaks in the same region (Derrick, Stulik & Landry 1999, p. 103) (fig. 31). Since chalk is identified as the only pigment used in the ground layer, it is possible that the binding medium is proteinaceous, i.e., an animal glue. Chalk is usually not used alone as a pigment in oil paint, because its low refractive index makes it transparent when mixed with oil (Gettens, West Fitzhugh & Feller 1993, p. 206). The porous ground layer may have absorbed oil from the succeeding paint layer, which is the light brown imprimatura. In the cross sections, there is no distinct line between ground layer and the imprimatura, which also may indicate that oil is absorbed into the ground layer (fig. 20). One has to keep in mind that, because of the repeated consolidation with sturgeon glue, proteins could possibly be found anywhere in the paint layers. A fiber from the canvas support is analyzed with FTIR to detect traces of the sizing, another animal glue. The acquired spectrum shows protein peaks, but it is impossible to tell if these originate from an animal glue used for sizing, or from the sturgeon glue used for consolidation.

The visual appearance of the paint layer suggests that the binding medium is oil, and this seems to be confirmed in the FTIR-analysis. To avoid the varnish interfering with the spectrum, a paint sample from an unvarnished area is analyzed with FTIR. The spectrum shows the significant peaks for oil mentioned above, and seemingly at a higher ratio than in the ground layer. In the sample there are also peaks

indicating a protein, most likely this protein is from the sturgeon glue consolidation (appendix 3, p. 51). The FTIR-spectrum of a sample of the varnish suggests it is a natural triterpenoid resin. The peaks in the hydrocarbon stretching region at 2944 cm^{-1} and 2853 cm^{-1} and in the carbonyl stretching region at 1707 cm^{-1} are strong and correlate with the absorption bands of a triterpenoid resin (Derrick, Stulik & Landry 1999, p. 104). The significant peaks for a mastic resin are seen in the fingerprint region of the spectrum, suggesting that the varnish is a mastic resin varnish (Azémard et al 2014, p.138) (appendix 3, pp. 51-52). The greenish fluorescence visible in UV-light is also an indication that the varnish may be an aged triterpenoid varnish (aiccm.org).

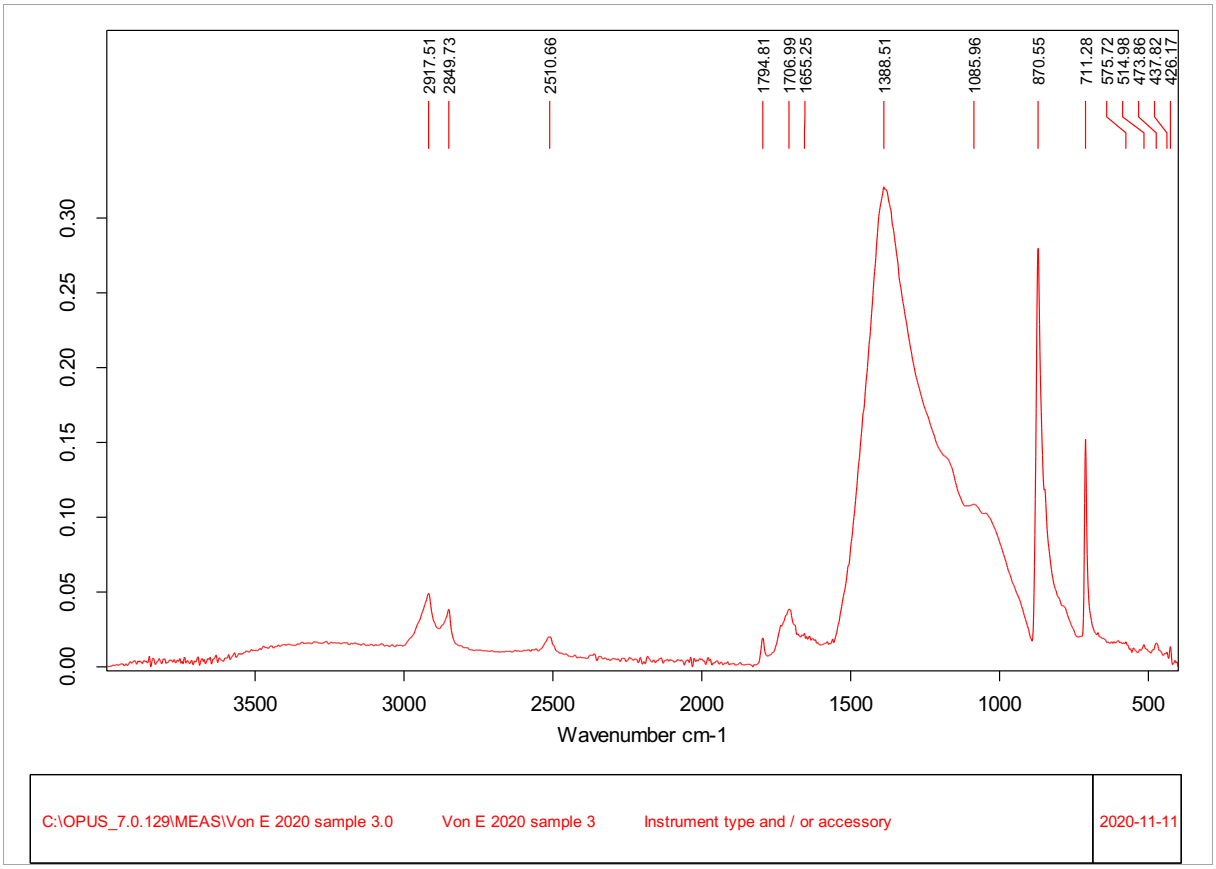


Figure 31. FTIR spectrum of sample 3, ground layer.

The FTIR-spectrum from a sample of the paint used for the 1950s retouches is a little hard to interpret at first. Acetone is added to the sample in an attempt to dissolve it and possibly get a clearer spectrum. The paint does not dissolve in the acetone, which is an indication that the binder is not an acrylic (Burke 1984). When the acetone is evaporated, the sample is analyzed again. The peaks significant for oil can be distinguished, and it is concluded that the paint is likely an oil paint. FTIR analysis of the waxy material used for consolidation in some areas confirms that the material is beeswax. A sample of what appears to be flaking excess adhesive is also analyzed and shows peaks significant for proteins mentioned above, see appendix 1 for location (sample number 13, p. 46). It is concluded that the material is an adhesive of animal origin, possibly sturgeon glue from past consolidation treatments (appendix 3, pp. 52-53)

5.4. Climate monitoring

Climate data from the Green Chamber is collected over six months, October 2020 – April 2021. The result show temperatures down to –8°C and a relative humidity (RH) in the range 75 – 88 % in the winter months, and in some periods the daily fluctuation in RH is around 10 % (fig. 32). Of the two dataloggers installed in October, only one recorded data until April. The data-logger installed in the left corner of the south wall only recorded until the beginning of November, when mice apparently cut the cable connecting the sensor to the logger. The recorded data so far is compared between the two loggers. The climatic differences between the two locations appear to be minimal. It is concluded that the data recorded by the logger installed on the right side of the painting on the south wall is probably representative for the whole room. During the autumn and winter when the museum is closed for visitors the windows are completely blinded, implying that there is no local radiant heat from sunlight reaching the wall paintings during this period. No mould growth is detected on the wall paintings in the Green Chamber, even though the RH is far above the 60 % that is considered safe from this aspect. The low temperature in the Green chamber during the periods with high RH may be a factor hindering the mould growth, which is something that has been observed in other historic houses with unregulated indoor climate (Schulze 2013, p. 88).

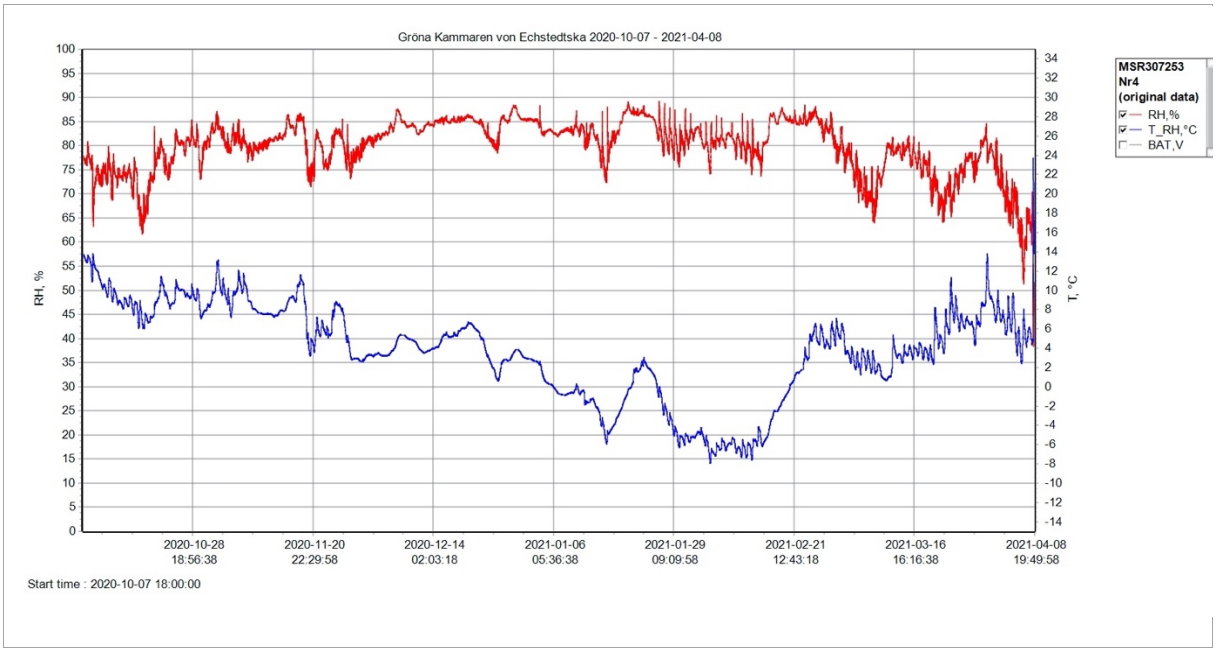


Figure 32. The indoor climate in the Green Chamber in the period Oktober 2020 – April 2021 recorded with an MSR datalogger. Blue line shows the temperature in °C with number on the right y-axis. Red line shows the relative humidity (RH) with a scale in percentage on the left y-axis.

6. DISCUSSION

The problem with reoccurring delamination of the paint layers is more or less restricted to the area to the left of the painting on the south wall. The problem seems possible to track back to the restoration in the 1950s, when layers of wallpaper were removed from the wall paintings. The extensive paint losses from this intervention are visible in archival photographs, and the retouches of these losses can be seen in the painting today. Extensive cracking, delamination and paint loss result in more surface area, as well as exposure of the porous ground layer otherwise protected by paint. More surface area implies that external factors like the climate, and added materials like varnish and adhesive, have more material to interact with and adhere to in that specific area, compared to in other areas.

The SEM-BSE images together with the result from SEM-EDX suggest there is lead soap present in the paint layers. Delamination of paint layers is a degradation phenomenon associated with metal soaps in paintings, as is increased transparency and darkening. The area in the painting most affected by delamination is also the area where the darkening of the paint is most striking. The formation of metal soaps is enhanced by water molecules, both in the form of humidity and water, and by solvents. The amount of water added to the paint layers during consolidation with sturgeon glue can be quite significant, and varnish is applied with solvents. As mentioned earlier, both water and solvents have the ability to hydrolyze the ester bonds in the triglycerides in the oil binding medium, and thereby enable the formation of metal soap (pp. 16-17). Oils can also promote the formation of metal soaps, by being a source of free fatty acids. Since the 1950s retouches seem to be oil-bound, and are extensive in this area, it is possible that they too have promoted the supposed lead soap formation. In this way, by paint loss and subsequent interference by other factors, it is possible that the 1950s wallpaper removal created an area of the painting that has the right conditions for lead soap to be formed.

The two cross sections, in which the presumed lead soap is detected, are selected for the SEM-EDS analysis with the criteria that they together should have all paint layers represented. The samples from which these cross sections are made, are from minor areas of delamination and not from the worst affected area. The findings in these cross sections can therefore not be regarded as representative for the condition of the paint in the most affected area. It would be interesting to analyze a cross section from the worst affected area with SEM-BSE and compare the lead white pigment particles from the different areas in the BSE-images. It would also be interesting to do micro-FTIR analysis of the supposed lead soap aggregates, to be able to positively confirm or reject the theory that there is pure crystalline lead soap in these areas.

Lead soap or no lead soap, the climatic conditions in the von Echstedt manor constitutes a risk for a painting with severe paint delamination. It is important in this case to notice that despite the rather extreme climate, an RH up to 88% and temperatures down to -8°C, the vast majority of painted surfaces inside the manor are well preserved. The same can be said about the paintings in the Green Chamber. Although one area is severely deteriorating, the paintings are for a large part in a rather good condition. This indicates that the climatic conditions cannot be the factor that initiates the deterioration in the affected area, even though the climate may be making the problem worse. The coldest temperature

recorded in the climate monitoring, -8°C, is close to -10°C, which is the temperature where an oil paint becomes glassy and brittle. The glassiness could make a lifted paint break more easily. The sturgeon glue used for consolidation may increase the stress in the paint layers, as it expands and shrinks with the fluctuating RH to a greater extent than the oil paint. Considering that the sturgeon glue starts to lose strength at RH above 75%, the loss in strength may be significant in an RH at almost 90%. This may entail that the paint consolidated with sturgeon glue once again loses adhesion to the underlaying ground layer.

Since the delamination is taking place between the ground layer and the paint layer, this study does not focus as much on the interactions between the canvas support and the ground and paint layers. Even if the ground layer for the most part is well adhered to the canvas support, it is possible that the movements create tension in the interface between ground and paint layers. It was noted when visiting the von Echstedt manor in April, that after several months with an RH around 70-88%, the canvas seemed more stretched, and the deformations were not as prominent as they were the previous autumn. If the panting would be demounted for treatment and mounted on the wall again, it is important to consider these properties of the canvas. In the unvarnished area in the canvas on the east wall, the craquelure differs from patterns of cracks seen elsewhere in the paintings. It may be because the varnish, applied in the 1950s, restrains the paint so that it cracks at fewer points but with greater force. If that is the case, the paint in the unvarnished area would be less restrained and could possibly move together with the support. The result is a pattern of fine craquelure rather than the pattern of cracks and ridges present elsewhere in the painting.

7. CONCLUSION

The materials used for painting the Green chamber wall paintings are oil paints on a linen canvas support. The pigment used for the ground layer is chalk, and the binder is most likely an animal glue. On the ground layer there is a light brown imprimatura in which the brown pigment is identified as an ochre. The two pigments primarily used to paint the motif are identified as lead white and malachite. There are indications that the lead white has reacted with the oil binder to form lead soap. It seems that verdigris has been used in a transparent dark green paint, and that carbon black is present in some areas. The varnish, applied in the 1950s, is identified as a mastic varnish. The retouch paint from the 1950s seems to be an oil paint. From archival records and discussions with the museum's paintings conservator, it is evident that both sturgeon glue and beeswax have been used to consolidate the paint, and this is confirmed by material analysis.

An historic event that may have initiated, or at least intensified the deterioration, is the removal of the wallpapers that covered the wall paintings before the 1950s restoration. The removal of the wallpapers induced a lot of paint loss, especially in the area that today is the most affected by delamination of the paint layers. The extensive paint loss has created an area that is more susceptible to moisture. Most likely the unregulated indoor climate is enhancing the paint delamination in this area. This moisture susceptible area is also an environment where the conditions may promote lead soap formation. Lead soap formation is enhanced by the presence of water molecules, and also by solvents and oil. Due to the extensive paint loss, the area may have been more exposed to solvent from the varnish and oil from the retouch paint, compared to other areas.

The factors causing the deterioration, both internal to the painting and external, appear to be interrelated. The progression of one deterioration path seems to enable, or enhance, the other. As the climatically induced delamination progresses, more surface area is exposed, and the lead soap formation gets access to more water molecules, and vice versa. The attempts to consolidate the paint with sturgeon glue may have added to the problem in the long term. The diluted sturgeon glue provides water molecules that may promote the soap formation to continue. The sturgeon glue is sensitive to high and fluctuating RH and may cause further delamination due to the climatic conditions.

8. SUMMARY

The wall paintings in the Green Chamber were investigated with the purpose of gaining knowledge about the ongoing deterioration. In an area approximately 170 x 170 cm in the painting on the south wall, the paint layers are delaminating from the ground layer despite several attempts to consolidate. The research aimed to understand what is causing the deterioration. The paintings were examined in situ and documented in normal light, as well as in raking and UV-light, and with a portable usb-microscope. Samples were collected for microscopy and material analysis. Archival records were searched for information on previous treatments, and to track the progression of the deterioration over time. The same issues were discussed with the museum's paintings conservator. The unregulated indoor climate in the Green Chamber was recorded over six months (October 2020 – April 2021) and showed an RH up to 88 % and temperatures down to - 8°C in the winter months.

The wall paintings have a canvas support in which the fiber was identified as linen. The canvas is deformed, and a pattern of cracks is visible on most of the paintings' surface. With the exception of the area with severe delamination, the paint layers seemed well adhered. The area with delaminating paint layers also shows significant darkening of the paint. The cross sections of the paint layers showed the ground layer, a light brown imprimatura, and layers of paint in different hues of green and white. The pigments were identified with SEM-EDS and FTIR. Chalk was used in the ground layer, and the brown pigment used in the imprimatura is most likely an ochre. Carbon black and verdigris seemed to be present as well. The green and white pigments were identified as lead white and malachite. In the SEM-EDS and in the SEM-BSE images, there were signs that the lead white is reacting with the binding medium to form lead soap. Lead soap has been associated with both delamination and darkening of the paint. The binders and the varnish were identified with FTIR. In the ground layer both protein and oil were detected. A protein glue was probably used as binder in the ground layer, and the oil is probably from the adjacent imprimatura. The binder in the paint layers was identified as oil, and the varnish applied in the 1950s appeared to be a mastic varnish. The paint used for the 1950s retouch seemed to be an oil paint. Since the paintings have been repeatedly consolidated with sturgeon glue, protein was expected and also detected in most samples analyzed.

Before the restoration in the 1950s, the wall paintings in the Green Chamber were covered with several layers of wall papers. An archival photograph from after the wallpapers were removed, show extensive losses in the area that today is suffering from delamination. The wallpaper removal and the resulting losses seem to have created an area of the painting that is more sensitive and susceptible to moisture. A high and fluctuating RH can make the materials expand and contract, which may cause disruption between the paint layers and result in delamination. If lead soap is responsible for some of the deterioration, the access to water in this area may have enhanced the saponification. The interventions with varnishing and retouching in the 1950s, as well as later consolidation with water diluted sturgeon glue, may also have promoted the lead soap formation.

Tables and Figures

Photographs by the author unless otherwise stated.

Tables and figures in Appendices

Reference list

Written and Electronic Sources:

AICCM.org. A summary of Ultra-Violet fluorescent materials relevant to conservation. https://aiccm.org.au/national-news/summary-ultra-violet-fluorescent-materials-relevant-conservation accessed 2020-11-11

Alm, Göran (1997). Arkitekturen och inredningskonsten. In: Alm, Göran (ed.) (1997). *Signums svenska konsthistoria [Bd 7] Frihetstidens konst*. Lund: Signum, pp. 27-134

Ashley-Smith, Jonathan, Burmester, Andreas & Eibl, Melanie (eds.) (2013). Climate for collections: standards and uncertainties. London: Archetype Publications, in association with Doerner Institut, Munich

Azémard, C., Vieillescazes, M. & Ménager, M. (2014). Effect of photodegradation on the identification of natural varnishes by FT-IR spectroscopy. In: *Microchemical Journal* 112 (2014). Elsevier, pp. 137-149

Berg, J. van den (2002). Analytical Chemical Studies on Traditional Linseed Oil Paints, Ph.D. dissertation, University of Amsterdam, Amsterdam.

Bratasz, Łukasz. (2013). Allowable microclimatic variations in museums and historic buildings. Reviewing the guidelines. In: Ashley-Smith, Jonathan, Burmester, Andreas & Eibl, Melanie (eds.) (2013). *Climate for collections: standards and uncertainties*. London: Archetype Publications, in association with Doerner Institut, Munich, pp. 11-19

Broström, Ingela & Stavenow-Hidemark, Elisabet (2004). Tapetboken: papperstapeten i Sverige. Stockholm: Byggförlaget

Buck, Susan L., Olley, Peggy & Wolbers, Richard (2012). Cross-section Microscopy and Fluorescent Staining. In: Joyce Hill & Rushfield, Rebecca Anne (eds.). *The conservation of easel paintings.* 1st ed. Abingdon, Oxon [England]: Routledge, pp. 326-335

Burke, J. (1984). Solubility Parameters: Theory and Application. In: *The Book and Paper Group Annual* (1984). Washington, D.C.: Book and Paper Group, American Institute for Conservation of Historic and Artistic Works https://cool.culturalheritage.org/coolaic/sg/bpg/annual/v03/bp03-04.html

Burnstock, Aviva (2019). Taking different Forms: Metal Soaps in Paintings, Diagnosis of Condition, and Issues for Treatment. In: Casadio, Francesca, Keune, Katrien, Noble, Petria, Loon, Annelies van, Hendriks, Ella, Centeno, Silvia A., Osmond, Gillian & Dibbits, Taco. (eds.). *Metal soaps in art: conservation and research.* Cham: Springer, pp. 243-262

Casadio, Francesca, Keune, Katrien, Noble, Petria, Loon, Annelies van, Hendriks, Ella, Centeno, Silvia A., Osmond, Gillian & Dibbits, Taco. (eds.) (2019). Metal soaps in art: conservation and research. Cham: Springer

CCI Canadian Conservation Institute (2010). The Identification of Natural Fibres. In: *CCI Notes 13/18.* Ottawa: Canadian Conservation Institute

Cederlund, Johan (1995). Von Echstedtska gården, Västra Smedbyn. Karlstad: Länsstyr. i Värmlands län

Cederlund, Johan (1997). Arkitekturen 1690 - 1730. In: Alm, Göran (ed.) (1997). *Signums svenska konsthistoria [Bd 6] Barockens konst*. Lund: Signum

Clavir, Miriam (2009). Conservation and Cultural Significance. In: Richmond, Alison & Bracker, Alison Lee (ed.) (2009*). Conservation principles, dilemmas and uncomfortable truths*. 1st ed. Amsterdam: Elsevier/Butterworth-Heinemann

Creswell, John W. & Poth, Cheryl N. (2017). Qualitative inquiry and research design: choosing among five approaches. Fourth edition. Los Angeles: Sage Publications

Derrick, Michele R., Stulik, Dusan & Landry, James M. (1999). Infrared spectroscopy in conservation science [Elektronisk resurs]. Los Angeles: Getty Conservation Institute http://www.getty.edu/conservation/publications/pdf_publications/infrared_spectroscopy.pdf

Erhardt, D., Tumosa, C.S., Mecklenburg, M.F. (2005). Long-Term Chemical and Physical Processes in Oil Paint Films. In: *Studies in Conservation* 50:2 2005, pp. 143-150

E.C.C.O. (European Confederation of Conservator-Restorers Organizations) (2003). E.C.C.O. professional Guidelines Code of Ethics, Brussels 7 March 2003

Estaugh, Nicholas (2004). The pigment compendium: a dictionary of historical pigments. Oxford: Elsevier Butterworth-Heinemann

Fridell Anter, Karin & Wannfors, Henrik (1997). Så målade man: svenskt byggnadsmåleri från senmedeltid till nutid. 2. [updated and extended.] ed. Stockholm: Svensk byggtjänst

Gettens, R. J., West Fitzhugh, E. & Feller, R. L. (1993). Calcium Carbonate Whites. In: Feller, Robert L. & Roy, Ashok (eds.) (1993). *Artists' pigments: a handbook of their history and characteristics. Vol. 2.* Washington: National Gallery of Art, pp. 203-244

Gettens, R. J., Kühn, H. & Chase, W. T. (1993). Lead White. In: Feller, Robert L. & Roy, Ashok (eds.) (1993). *Artists' pigments: a handbook of their history and characteristics. Vol. 2.* Washington: National Gallery of Art, pp. 67-79

Gettens, R. J. & West Fitzhugh, E. (1993). Malachite and Green Verditer. In: Feller, Robert L. & Roy, Ashok (eds.) (1993). *Artists' pigments: a handbook of their history and characteristics. Vol. 2.* Washington: National Gallery of Art, pp. 183-196

Goldstein, Joseph (2018). Scanning Electron Microscopy and X-Ray Microanalysis. Fourth edition New York, NY: Springer

Grate, Pontus (1997). Bildkonsten. In: Alm, Göran (ed.) (1997). *Signums svenska konsthistoria [Bd 7] Frihetstidens konst*. Lund: Signum, pp. 168-263

Hallén, Åsa (2012). Västra Smedbyn - Restaureringen av von Echstedtska gården 1955-1957. In: Nilsson, Käthy, Hallén, Åsa, Sjöqvist, Lars, Jansson, Annelie & Collvin, Birgitta (ed.) (2012). *von Echstedtska gården*. Karlstad: Stiftelsen Värmlands museum, pp. 118-135

Helou-de La Grandiere, P., Le Hô, A.-S. & Mirambet, F. 2008. Delaminating Paint Films at the End of 1950s: A Case Study on Pierre Soulages. In: J.N. Townsend, T. Doherty, G. Heydenreich & J. Ridge, (eds). *Preparation for Painting: The Artist's Choice and Its Consequences*. London: Archetype, pp. 156–62.

Hendrickx, R, Desmaraisb, G., Wederd, M., Ferreiraa, E.S.B., Deromee, D. (2016). Moisture uptake and permeability of canvas paintings and their components. In: *Journal of Cultural Heritage* 19 2016, pp. 445-453

Hermans, J. J. (2017). Metal soaps in oil paint: Structure, mechanisms and dynamics. Dissertation. University of Amsterdam

Hermans, Joen j., Keune, Katrien, Van Loon, Annelies, Iedema, Piet D. (2019). Toward a Complete Molecular Model for the Formation of Metal Soaps in Oil Paints. In: Casadio, Francesca, Keune, Katrien, Noble, Petria, Loon, Annelies van, Hendriks, Ella, Centeno, Silvia A. & Osmond, Gillian (eds.) (2019). *Metal soaps in art: conservation and research*. Cham: Springer

Hermerén, Karin (2014). Den utsatta konsten: att förvalta konst i offentlig miljö - etik, lagstiftning och värdeförändring. Licentiatavhandling Göteborg : Göteborgs universitet, 2014

ICON (2019). The Institute of Conservation, Ethical Sampling Guidance January 2019

IRUG 2021. Infrared and Raman Users Group, Spectral Database. http://www.irug.org , accessed 2020-11-03

IRUG 2021. Spectrum IMP00115. Infrared and Raman Users Group, Spectral Database, http://www.irug.org/jcamp-details?id=1801, accessed 2020-11-05

Keune, Katrien & Boon, Jaap J. (2007). Analytical Imaging Studies of Cross-Sections of paintings Affected by Lead Soap Aggregate Formation. In: *Studies in Conservation*, *Vol. 52, No. 3* (2007). Taylor & Francis Ltd. pp. 161-176

Keune, K., van Loon, A. & Boon, J. J. (2011). SEM Backscattered-Electron images of Paint Cross Sections as Information Source for the Presence of the Lead White Pigment and Lead-Related Degradation and Migration Phenomena in Oil Paintings. In: *Microscopy and Microanalysis.* Cambridge University Press, 17(5), pp. 696–701

Keune, K., Kramer, R.P., Huijbregts, Z., Schellen, H.L., Stappers, M.H.L., van Eikema Hommes, M.H. (2016). Pigment Degradation in Oil Paint Induced by Indoor Climate: Comparison of Visual and Computational Backscattered Electron Images. In: *Microscopy and Microanalysis 22(2)*, Microscopy Society of America, pp. 448-457

Kühn, H. (1986). *Zink white*. In: Feller, Robert L. & Feller, Robert L (eds.) (1986). Artists' pigments: a handbook of their history and characteristics. Vol. 1. Washington: National Gallery of Art, pp. 169-186

Kühn, H. (1993). Verdigris and Copper Resinate. In: Feller, Robert L. & Roy, Ashok (eds.) (1993). *Artists' pigments: a handbook of their history and characteristics. Vol. 2.* Washington: National Gallery of Art, pp. 131-154

van Loon, A., Noble, P., Burnstock, A. (2012). Ageing and deterioration of traditional oil and tempera paints. In: Stoner, Joyce Hill & Rushfield, Rebecca (ed.) 2012. *The conservation of easel paintings*, New York: Routledge Inc. pp. 214 – 241

Länstyrelsen Värmland (2007a). Värmländska Byggnadsminnen von Echstedtska gården. PDF. http://extdokument.lansstyrelsen.se/Varmland/Dokumentarkiv/Kulturmiljo/Byggnadsminnen/von_echstedtska_garden.pdf accessed: 2021-02-22

Länsstyrelsen Värmland (2007b). Riksintresse för kulturmiljövården Västra Smedbyn. PDF. https://www.lansstyrelsen.se/download/18.2c30d6f167c5e8e7c0d267/1546934504059/k36_saffle_v_smedbyn.pdf accessed 2021-05-10

Mecklenburg, M. F. (2005). The structure of canvas supported paintings = La estructura de la pintura sobre lienzo. In: Castell Agustí, M. et al. (eds) *Libro de actas = Preprints: Interim meeting: International Conference on Painting Conservation: canvases, behaviour, deterioration & treatment = Seminario Internacional de Conservación de Pintura: el soporte textil,*

comportamiento, deterioro y criterios de intervención. Valencia: Universidad Politécnica de Valencia, Valencia, Spain, pp. 119-155

Mecklenburg, M. F. and Tumosa, C. S. (1991) Mechanical behavior of paintings subjected to changes in temperature and relative humidity. In: *Art in transit.* Washington D.C: National Gallery of Art, Washington D.C, United States, pp. 173-216

Mecklenburg, M. F. (ed.) (1991). *Art in transit.* Washington D.C: National Gallery of Art, Washington D.C, United States

Michalski, S. (1991) 'Paintings - their response to temperature, relative humidity, shock, and vibration'. In: Mecklenburg, M. F. (ed.) *Art in transit.* Washington D.C: National Gallery of Art, Washington D.C, United States, pp. 223-248

Mills, John Stuart & White, Raymond (1994). The organic chemistry of museum objects. 2. ed. Oxford: Butterworth-Heinemann

Muñoz Viñas, Salvador (2005). Contemporary theory of conservation. Oxford: Elsevier Butterworth-Heinemann

Nilsson, Käthy, Hallén, Åsa, Sjöqvist, Lars, Jansson, Annelie & Collvin, Birgitta (eds.) (2012). Von Echstedtska gården. Karlstad: Stiftelsen Värmlands museum

Nilsson, Käthy (2012). Rundtur på von Echstedtska gården. In: Nilsson, Käthy, Hallén, Åsa, Sjöqvist, Lars, Jansson, Annelie & Collvin, Birgitta (eds.) (2012). *Von Echstedtska gården*. Karlstad: Stiftelsen Värmlands museum, pp. 14 - 59

Noble, P., van Loon, A. and Boon, J.J. (2008). Selective darkening of groung and paint layers associated with the wood structure in seventeenth-century panel paintings. In: J.N. Townsend, T. Doherty, G. Heydenreich & J. Ridge, (eds). *Preparation for Painting: The Artist's Choice and Its Consequences.* London: Archetype, pp. 156 – 62.

Nodermann, Maj (1997). På väggar och tak. In: Alm, Göran (ed.) (1997). *Signums svenska konsthistoria [Bd 7] Frihetstidens konst*. Lund: Signum, pp. 419 – 433

Nyström, Ingalill (2012). Bonadsmåleri under lupp: spektroskopiska analyser av färg och teknik i sydsvenska bonadsmålningar 1700-1870. Diss. Göteborg : Göteborgs universitet, 2012

Olausson, Peter (2012). Bengt von Echstedt i arkiven. In: Nilsson, Käthy, Hallén, Åsa, Sjöqvist, Lars, Jansson, Annelie & Collvin, Birgitta (eds.) (2012). *von Echstedtska gården*. Karlstad: Stiftelsen Värmlands museum, pp. 60-93

von Reden, A. (2013). Uncertainties in the interaction between a canvas painting support and moisture. In: Ashley-Smith, J., Burmester, A., and Eibl, M. (eds) *Climate for collections: standards and uncertainties*. London: Archetype Publications Ltd., London, United Kingdom, pp. 247-256

Reedy, Terry J. & Reedy, Chandra L. (1992). Principles of experimental design for art conservation research [Elektronisk resurs]. Newark, Del.: Stat/Consul http://www.getty.edu/conservation/publications/pdf_publications/principles_experiment.pdf

Riegl, Alois (1903). The Modern Cult of Monuments: Its Character and Its Origin. trans. Kurt W. Forster and Diane Ghirardo. In *Oppositions*, n. 25 (Fall 1982), pp. 21-51

Schulze, Andreas (2013). How the usual museum climate recommendations endanger our cultural heritage. In: Ashley-Smith, Jonathan, Burmester, Andreas & Eibl, Melanie (eds.) (2013). *Climate for collections: standards and uncertainties*. London: Archetype Publications, in association with Doerner Institut, Munich, pp. 80-92

Scott, David A. (2002). Copper and bronze in art: corrosion, colorants, conservation. Los Angeles, Calif.: Getty Conservation Institute

Smith, Brian C (1999). Infrared spectral interpretation: a systematic approach. Boca Raton: CRC Press

Stols-Witlox, Maartje (2012). Grounds, 1400–1900. In: Stoner, Joyce Hill & Rushfield, Rebecca (ed.) 2012. *The conservation of easel paintings*, New York: Routledge Inc., pp. 161-188

Stuart, Barbara (2007). Analytical techniques in materials conservation [Elektronisk resurs]. Chichester: John Wiley & Sons, Ltd.

Sutherland, K. (2003). Solvent-Extractable Components of Linseed Oil Paint Films. In: *Studies in Conservation* 48 2003, pp. 111-135

US/ICOMOS International Symposium (2003). Managing change: sustainable approaches to the conservation of the built environment : 4th Annual US/ICOMOS International Symposium organized by US/ICOMOS, Program in Historic Preservation of the University of Pennsylvania, and the Getty Conservation Institute 6-8 April 2001, Philadelphia, Pennsylvania. Los Angeles: Getty Conservation Institute

van de Vall, R., Hölling, H., Scholte, T., & Stigter, S. (2011). Reflections on a biographical approach to contemporary art conservation. In: J. Bridgland (ed.), ICOM-CC: 16th Triennial Conference, Lisbon, 19-23 September 2011: preprints Critério

Villers, Caroline (2004). Post minimal intervention. In: *The Conservator, 28:1*, pp. 3-10

Feller, Robert L. (ed.) (1986). Artists' pigments: a handbook of their history and characteristics. Vol. 1. Washington: National Gallery of Art

Vos, Lisette, Harmanni, Richard, Verslype, Ige, De Fouw, Jozsephina, Reynaerts, Jenny & van Eikemma Hommes, Margriet (2015). Researching and Presenting Fragments of Late 17th- and 18th-Century Dutch Painted Chambers: “Re-Presenting” Jurriaan Andriessen (1743-1819), a Case Study. In: *AIC Paintings Specialty Group postprints volume 28, 2015.* Washington, D.C.: Paintings Specialty Group, American Institute for Conservation of Historic and Artistic Works, pp. 99-116

Walliman, Nicholas (2011). Research methods: the basics. London: Routledge

Oral Sources:

Source 1: Skoglund, Cecilia. Paintings Conservator at Värmlands museum

Archives:

Karlstad

Värmlands museums arkiv (Vm)

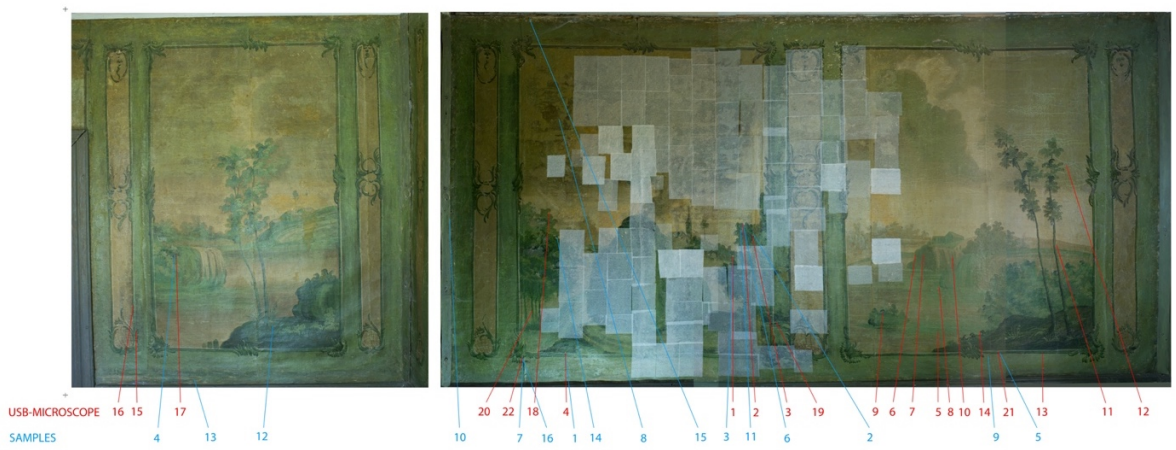
- Värmlands museums Byggnadsminneshandlingar Värmlands län, Byggnadsminnen 28 von Echstedtska gården 6.
- Värmlands museums Byggnadsminneshandlingar Värmlands län, Byggnadsminnen 28 von Echstedtska gården 4.

Appendices

Appendix 1. Map of sites for samples and usb-micrographs

See following pages for a larger map and micrographs of the sites for samples number 5 and 7.

Table 1. Map of sites for samples and usb-micrographs with sample descriptions.



SAMPLES	Green Chamber von Echstedt manor (Gröna Kammaren von Echstedtska gården)				
Sample number	Collected date	Description	Usb-microgr. Area	Macro photo	Type of Analysis
1	2020-09-08	Paints	4		Cross section
2	2020-09-08	Paints	6		Cross section
3	2020-09-21	Ground	1		FTIR
4	2020-09-24	Paints	17		Cross section
5	2020-10-07	Paints	21		Cross section, SEM
6	2020-10-07	Paints	2		Cross section
7	2020-10-07	Paints	22		Cross section, SEM, FTIR
8	2020-10-07	Paints no varnish	-		Cross section FTIR
9	2020-10-06	Varnish	-		FTIR
10	2020-10-06	Varnish	-		FTIR
11	2020-10-06	Varnish	-		FTIR
12	2020-10-06	Varnish	-		FTIR
13	2020-10-06	Adhesive (cons?)	-		FTIR
14	2020-10-06	Wax (cons.)	-		FTIR
15	2020-10-07	Canvas fiber	-		microscopy
16	2020-10-07	Canvas fiber	22		microscopy
17	2020-10-07	Canvas fiber			microscopy
18	2020-10-07	Canvas with adhesive			FTIR
19	2020-10-07	Strip lining thread			microscopy
20	2020-10-07	Varnish			FTIR
21	2020-10-07	Retouch paint			FTIR

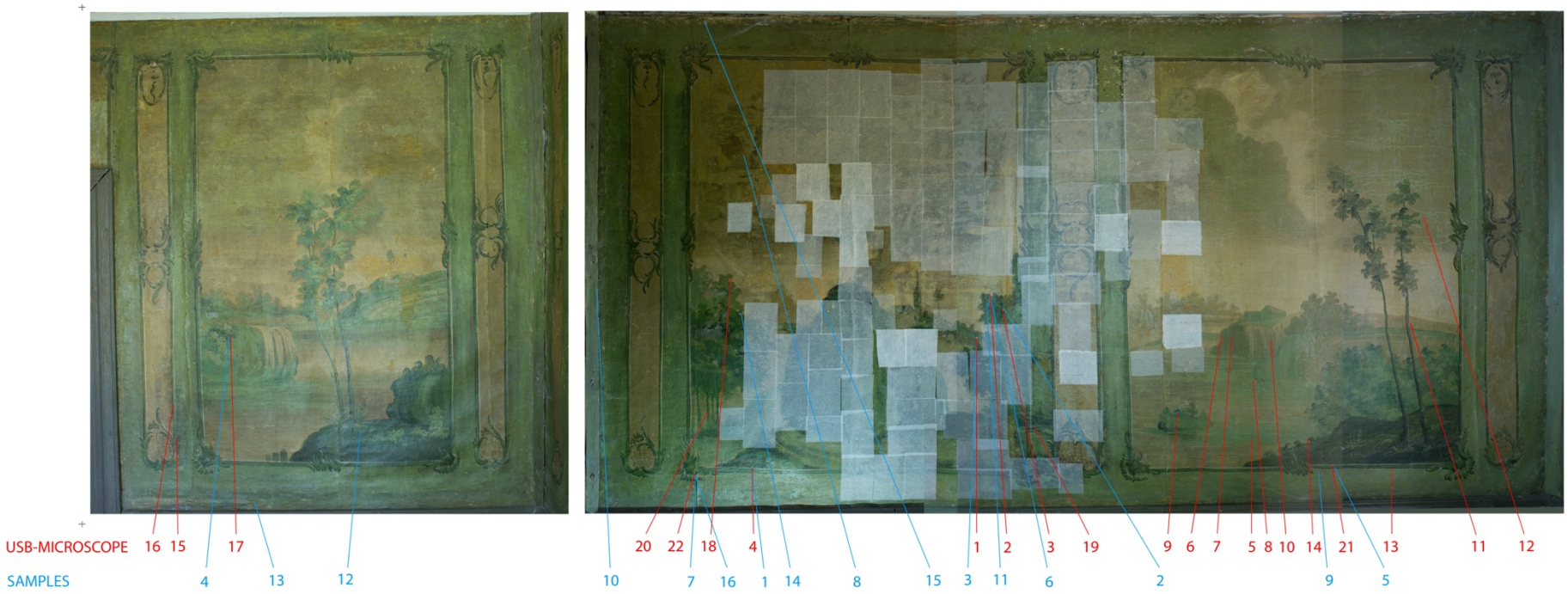
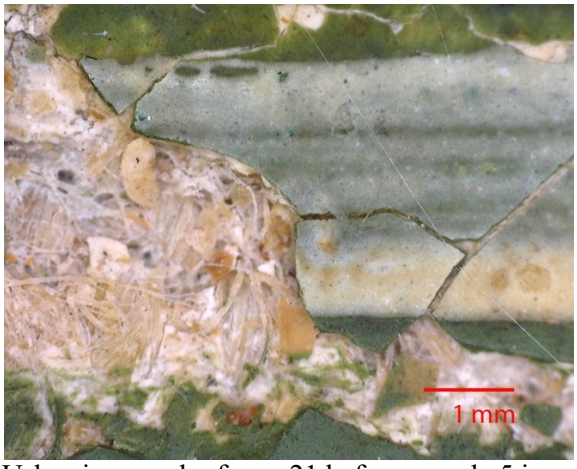
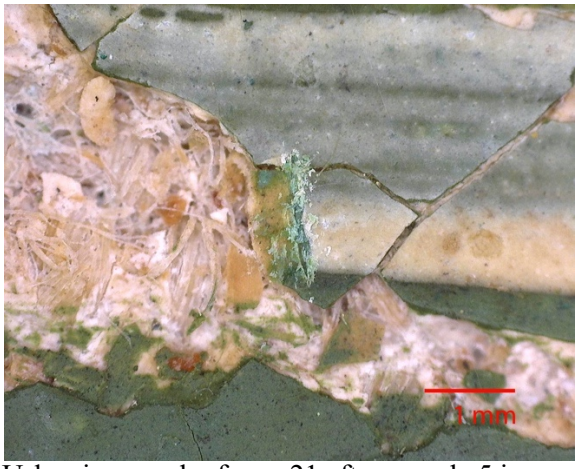


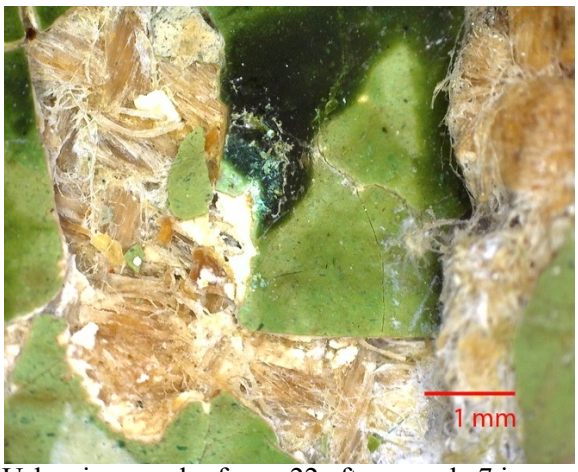
Figure 33. Map of sites for samples and usb-micrographs.

Table 2. Usb-micrographs of the areas where samples 5 and 7 are collected.

<table>
<tr><td colspan="2">Usb-micrographs of the areas where samples 5 and 7 are collected. The cross-sections used for pigment identification (cross-sections 5.1. and 7.1.) are made from these samples (see chapter 5.2. Pigment Identification)</td></tr>
<tr><td> 

Usb-micrograph of area 21 before sample 5 is collected.</td><td> 

Usb-micrograph of area 21 after sample 5 is collected.</td></tr>
<tr><td> 

Usb-micrograph of area 22 before sample 7 is collected.</td><td> 

Usb-micrograph of area 22 after sample 7 is collected.</td></tr>
</table>

Appendix 2. Overview photographs and maps

Figure 34 above. Overview collage of photographs of the wall paintings on the east and south walls. Figure 35 below. The wall paintings in UV-light.

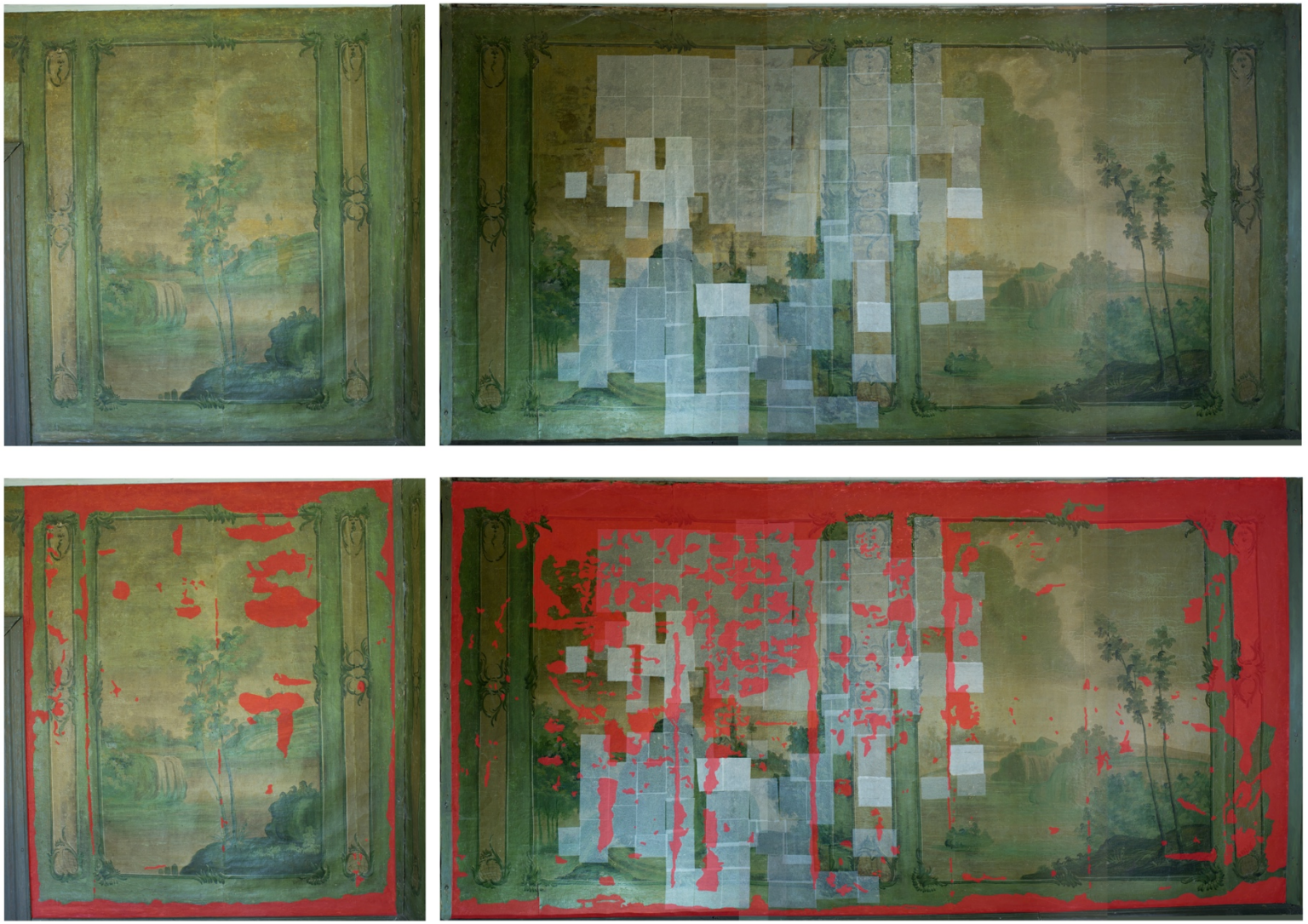


Figure 36 above. Overview collage of photographs of the wall paintings. Figure 37 below. Same collage as above with 1950s retouches mapped in red.

Appendix 3. FTIR- spectra

Table 3. FTIR-spectrum of paint layers, sample 8.

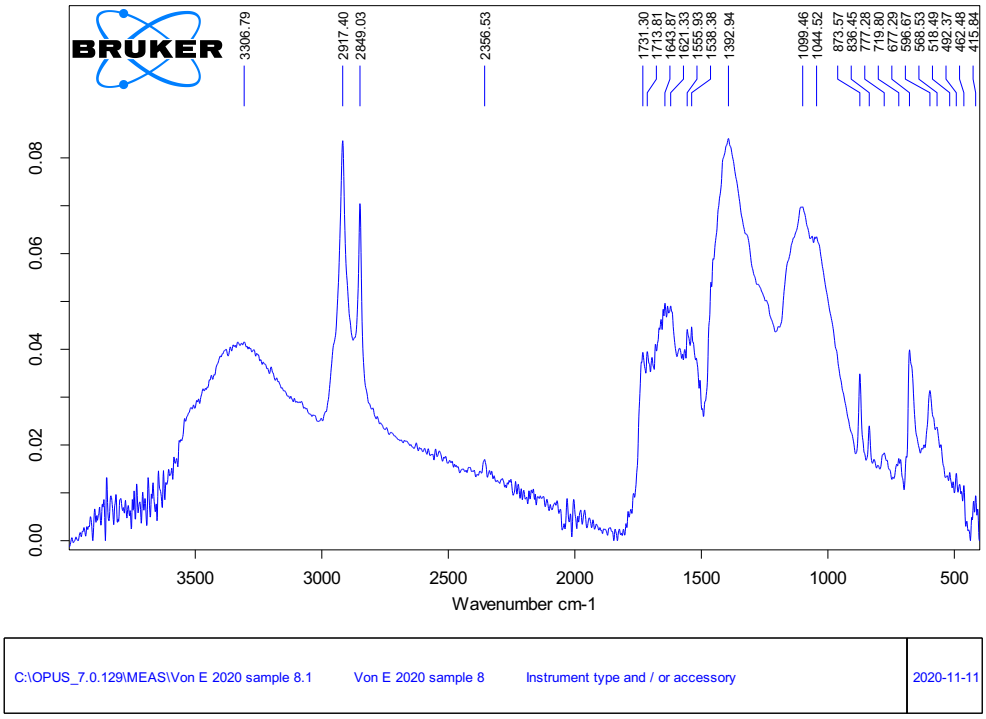


Table 4. FTIR-spectrum of varnish, sample 20.

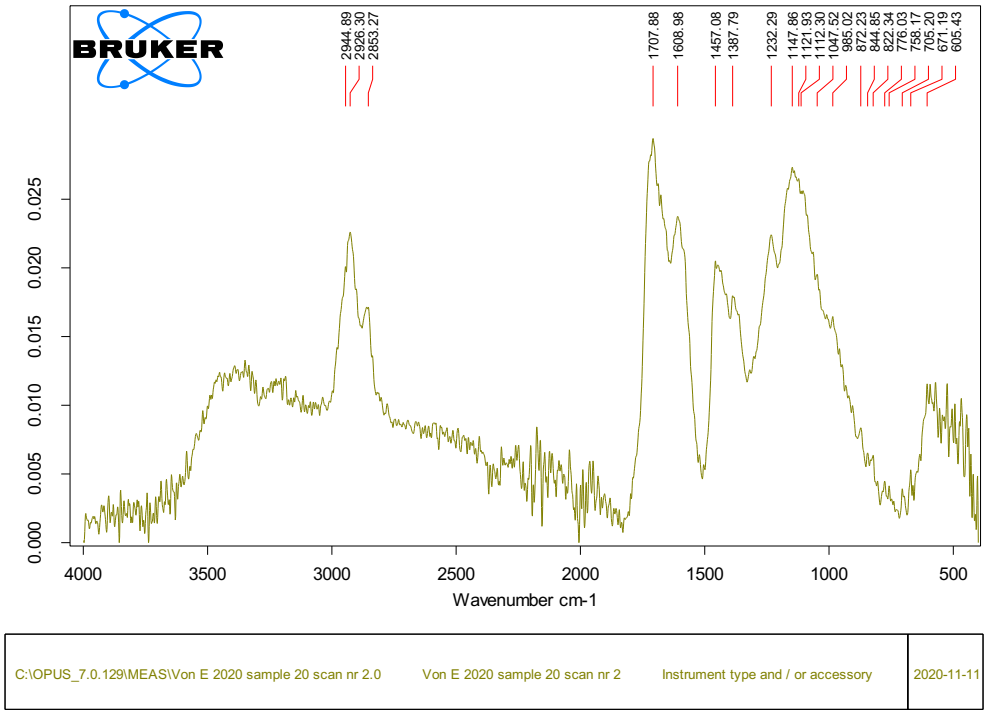


Table 5. FTIR-spectrum of varnish, close-up of fingerprint region, sample 20.

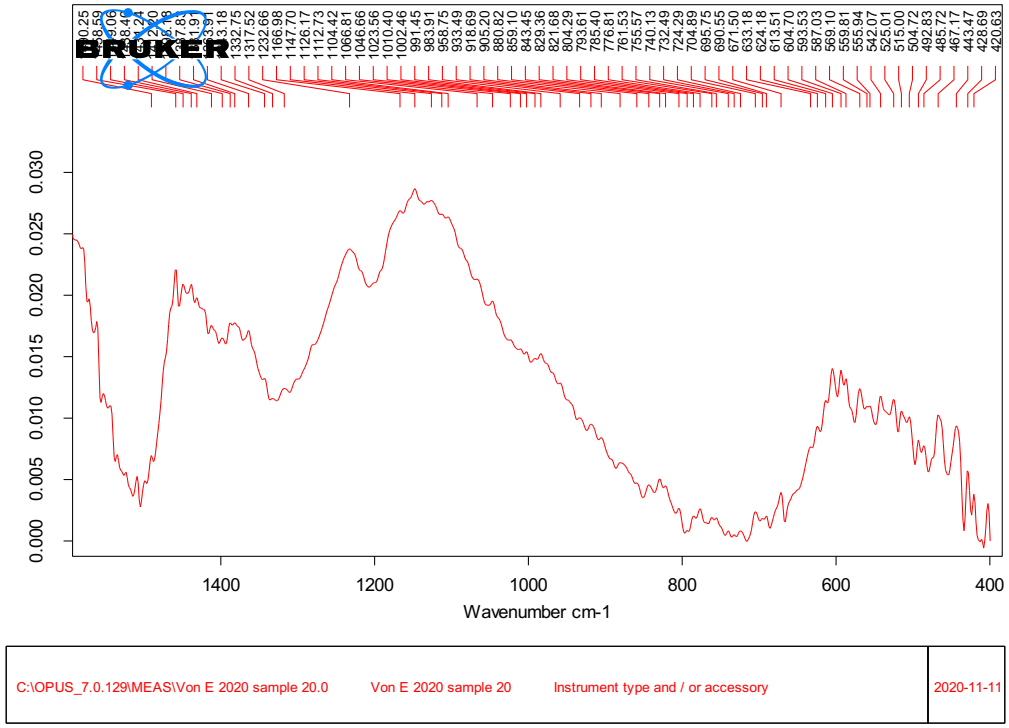


Table 6. FTIR-spectrum of 1950s retouch paint, sample 21.

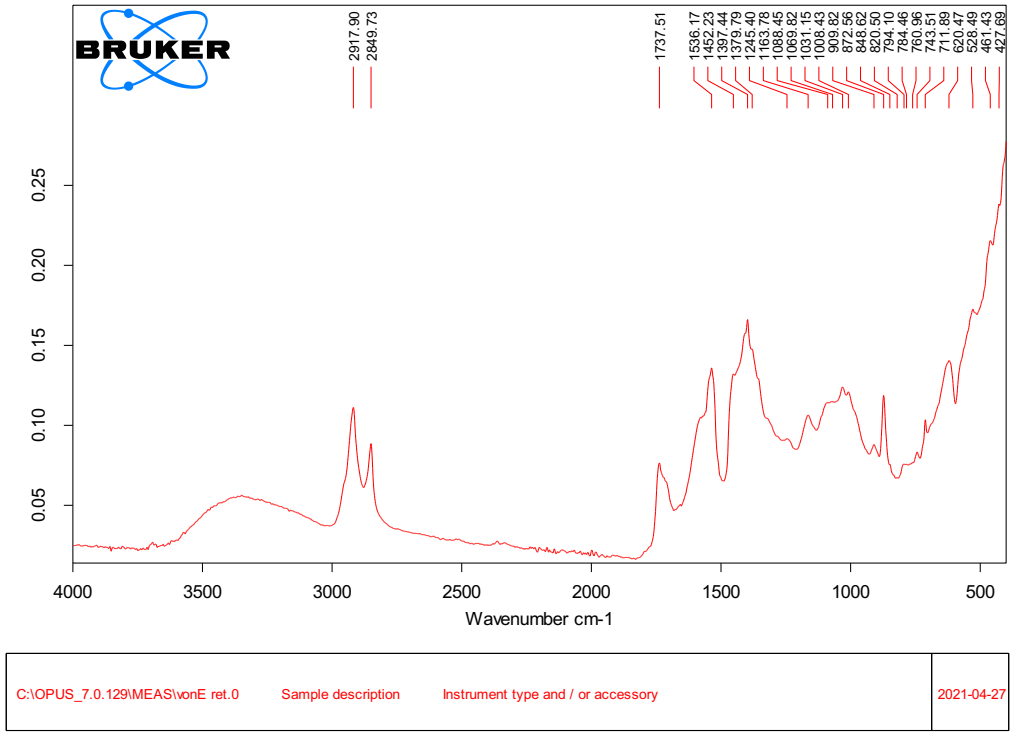


Table 7. FTIR-spectrum of adhesive, sample 13.

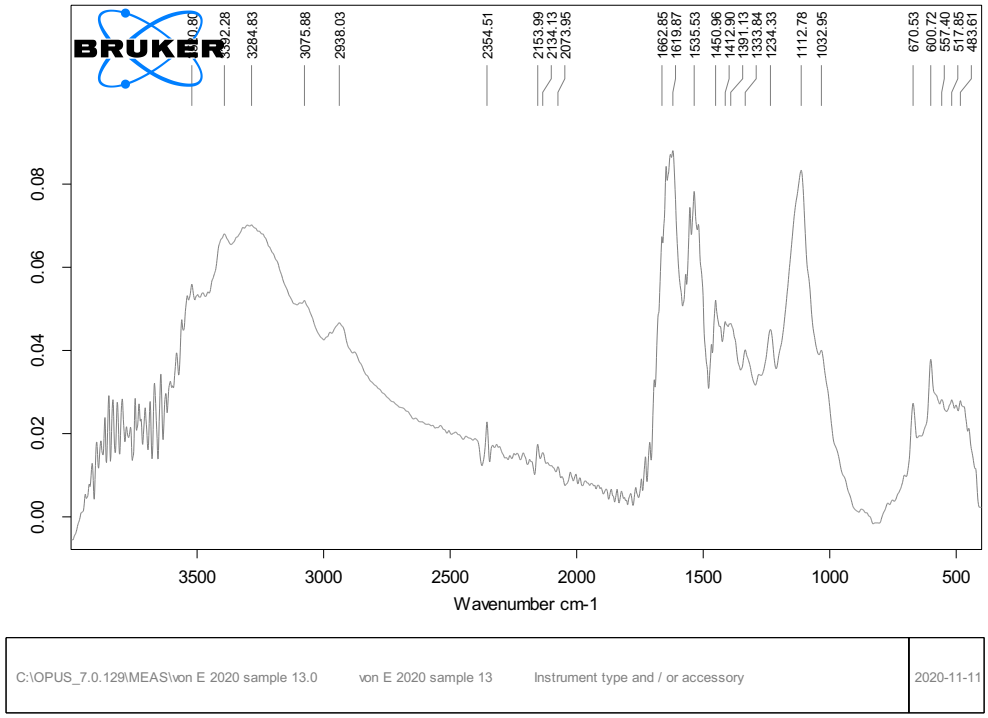
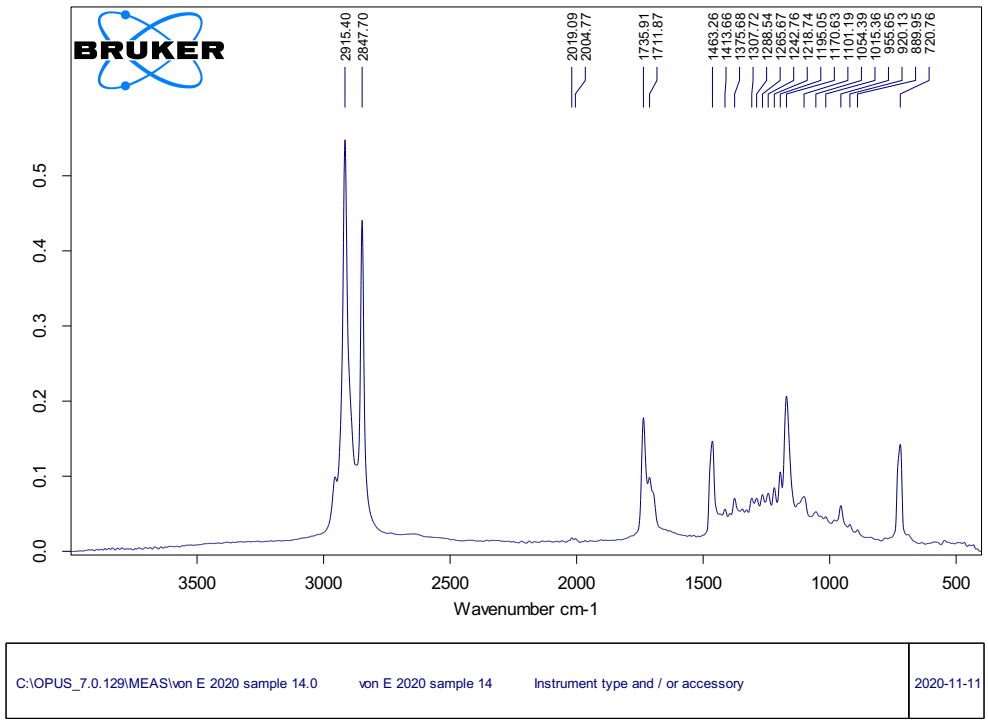


Table 8. FTIR-spectrum of wax, sample 14.



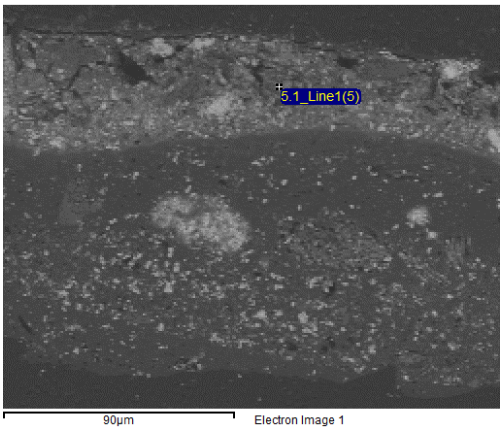
Appendix 4. SEM-EDS

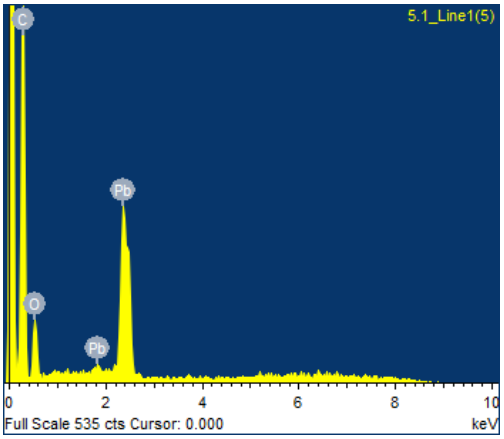
Table 9. SEM-EDS analysis of possible lead soap aggregate in cross section 5.1. (sample 5).

LisaBrandgren 12/02/2021 15:57:39

Sample: 5.1

Type: Default





Spectrum processing :

No peaks omitted

Processing option : All elements analyzed

Number of iterations = 2

Standard :

O Obsidian 18-May-2017 07:35 PM

Pb PbF2 1-Jun-1999 12:00 AM

Element	App Conc.	Intensity Corrn.	Weight %	Weight % Sigma	Atomic %
O K	1.21	1.5997	0.76	0.05	67.17
Pb M	4.62	0.9660	4.78	0.17	32.83
Totals			5.54		

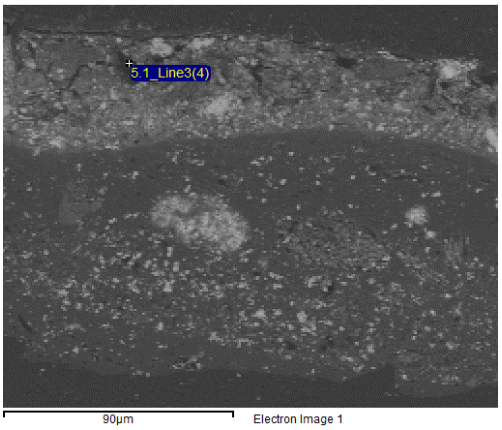
OXFORD INSTRUMENTS
The Business of Science®

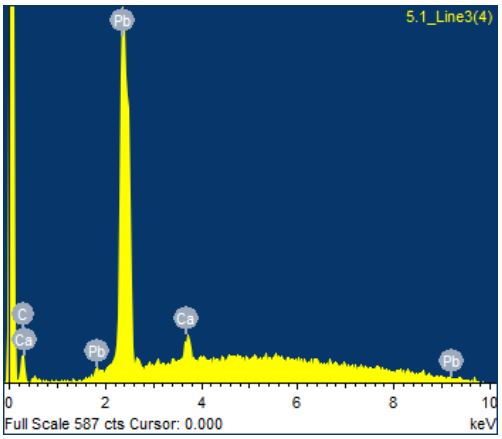
Table 10. SEM-EDS analysis of possible lead soap aggregate in cross section 5.1. (sample 5).

LisaBrandgren 12/02/2021 16:13:49

Sample: 5.1

Type: Default





Spectrum processing :

No peaks omitted

Processing option : All elements analyzed

Number of iterations = 2

Standard :

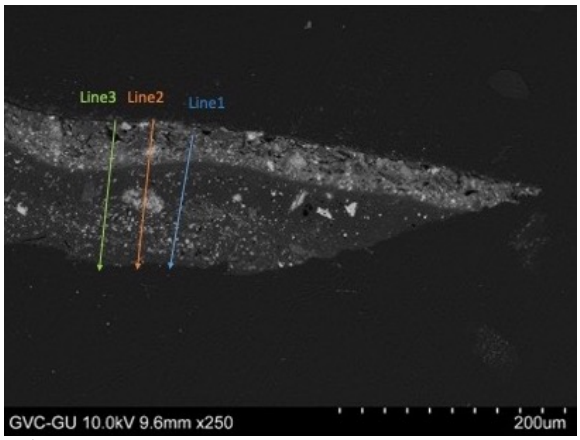
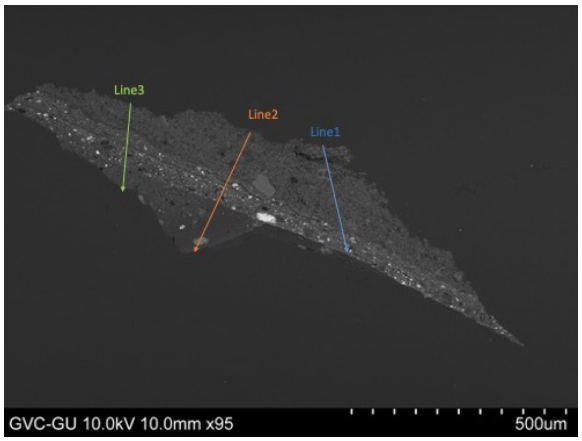
Ca MAC Wollastonite 15-Sep-2017 01:48 PM

Pb PbF2 1-Jun-1999 12:00 AM

Element	App Conc.	Intensity Corrn.	Weight %	Weight % Sigma	Atomic %
Ca K	0.82	1.3724	0.60	0.06	22.81
Pb M	10.73	1.0204	10.51	0.24	77.19
Totals			11.11		

OXFORD INSTRUMENTS
The Business of Science®

Table 11. SEM- BSE-images of cross-sections 5.1. and 7.1. with approximate positions of the lines for EDS-analysis.

BSE-images of cross-sections 5.1. and 7.1. with approximate positions of the lines for EDS-analysis	
 **5.1.**	Line 1: 30 points analyzed Line 2: 30 points analyzed Line 3: 30 points analyzed
 **7.1.** (please note that the cross section is upside down in this image)	Line 1: 30 points analyzed Line 2: 30 points analyzed Line 3: 25 points analyzed